Landslide and slope stability of Iowa

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Landslide and slope stability of Iowa

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Signatures have been redacted for privacy

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CHAPTER 1. INTRODUCTION

1.1 General Statement

Slope stability problems have occurred throughout history when the balance of natural soil slopes has been disrupted. Furthermore, the increasing demand for engineered cut and fill slopes on construction projects has increased the need to understand analytical methods, investigative tools, and stabilization methods to solve slope stability problems. An understanding of geology, hydrology, and soil properties is central to applying slope stability principles properly. Analyses must be based upon a model that accurately represents site subsurface conditions, ground behavior, and applied load. (Abramson et al, 1995)

Landslides and slope instability are a problem in most parts of Iowa. In the summer of 1998, Iowa State University geotechnical engineering researchers learned that Iowa county engineers had concerns regarding repair of landslides in highway cut slopes and embankments. The main problem of these engineers is that they do not have sufficient geotechnical expertise to determine the best method of landslide repair.

The objective of this research, which is part of a project funded by Iowa Department of Transportation, is to provide Iowa county engineers and highway maintenance personnel with a better understanding of landslide and slope instability interpretation and repair.

There are three major parts of this thesis. The first part is a summary and report of the landslide questionnaire results from the county engineers in the state of Iowa. The second part of the thesis is a guideline of stable height versus slope angle for different geologic parent materials. The final part is a slope failure case study in western Iowa.

CHAPTER 2. SCOPE OF LANDSLIDE PROBLEMS IN IOWA

2.1 Introduction

A survey of Iowa County engineers was conducted to assess the extent and nature of slope stability problems in the state and to determine successful repair methods. A questionnaire was prepared and sent to all the county engineers. The questions focused on landslides that have occurred since 1993. A copy of the questionnaire is included in the Appendix A. A total of 99 questionnaires were sent, and 60 were received giving a response rate of 61%. The percentages reported here are based on only the counties that responded to the questionnaire. The data from the survey were compared with the topographic map of the state and a correlation between frequency of landslides and relief was apparent. This resulted in a landslide susceptibility map, Figure 2.1, that categorizes regions of Iowa as either low risk, medium risk, or high risk regions for landslides. This map is an interpretative document based on incomplete data but does suggest regions of the state where landslides might be problematic.

2.2 The Statewide Distribution of Landslides

The data show that 48 counties, or 80% of those responding, have experienced landslides or slope stability problems. There are 44% of the counties with 1 to 5 landslides, 25% with 6 to 10 landslides, and 14% with 11 to 15 and 17% with more than 15 landslides since January 1993. Figure 2.2 summarizes the frequency of landslides on a statewide basis.

In the deep loess region of western Iowa, an average of 10 landslides occurred in counties that responded to the questionnaire. On the Nebraska border, there are 3 counties

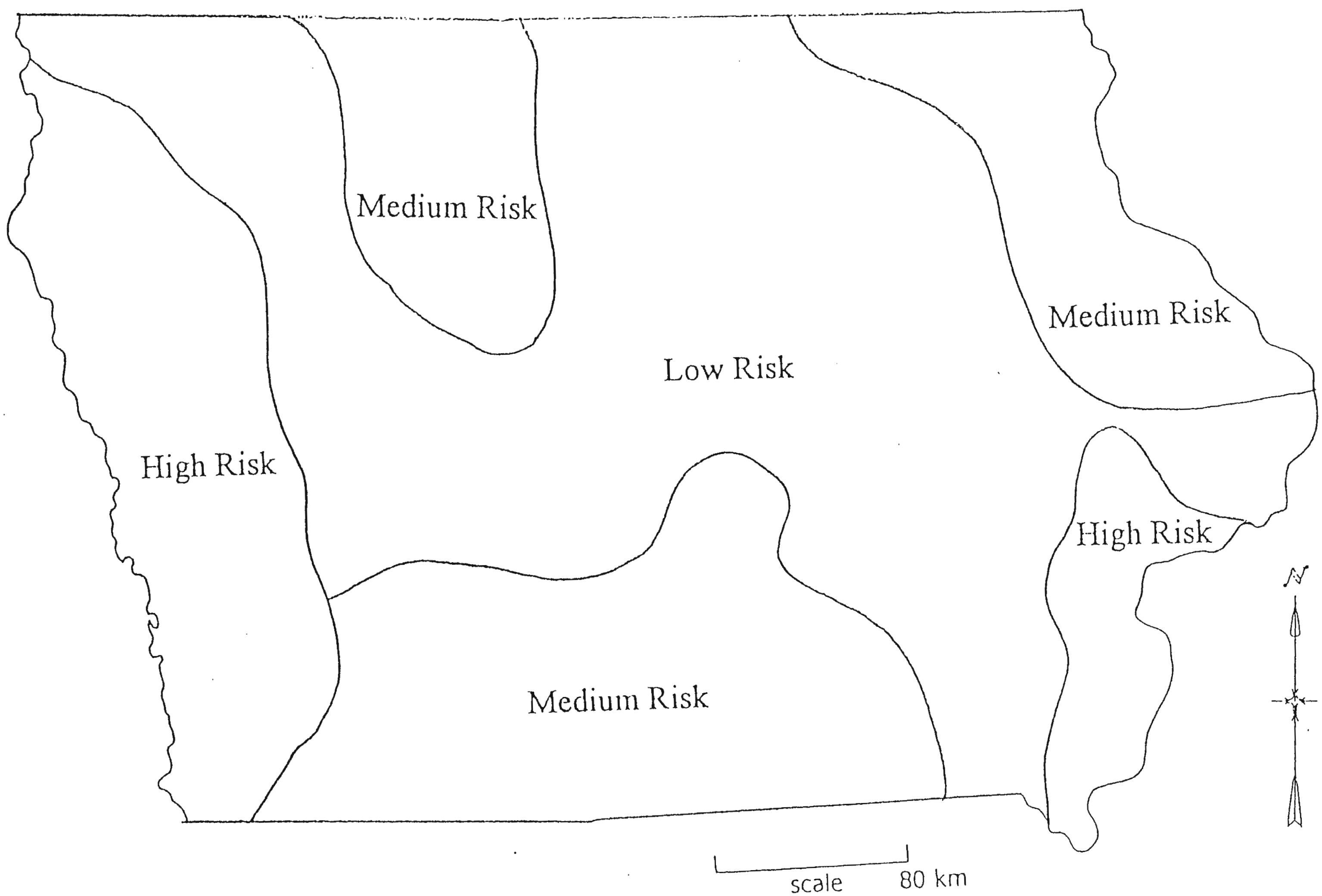


Figure 2.1 Iowa Landslide Risk Map

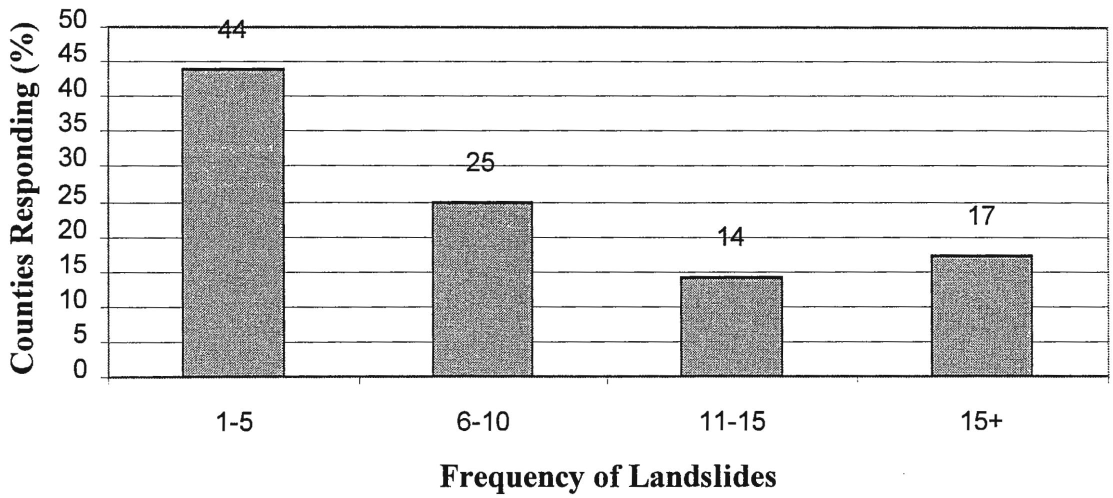


Figure 2.2 Frequency of Landslides

with more than 15 landslides and one county with 6-10 landslides. Two of the southern most counties have 1-5 landslides.

In the glacial till area of central Iowa an average of 5 landslides occurred in counties that responded to the questionnaire. Most of the counties in central Iowa have experienced 1-5 landslides; Emmet, Pocahontas, and Webster counties however, have reported 6-10 landslides. Most of the counties adjacent to the Des Moines lobe have no or 1-5 landslides except Cherokee County in north-western Iowa, and Madison and Jasper counties in southern Iowa that have experienced 11-15 landslides.

In the loess-mantled area, an average of 8 landslides occurred in the responding counties. Twelve of the counties have 1-5 landslides, and 7 counties have 6-10 landslides. Four counties in this region have 11-15 landslides: Allamakee and Clayton county in the northeastern part of Iowa, Jones county in the eastern part of Iowa, and Taylor county in southern Iowa. There are 4 counties with more than 15 landslides: Cedar in the east, Louisa and Lee in the southeast, and Monroe in the south-central part of Iowa. Most of the counties in the eastern part of Iowa have a significant number of landslides, ranging from 6 to more than 15, except Scott County with 1-5 landslides.

On a statewide basis, the soil most frequently associated with slope failures is undifferentiated fill with 28% of the failures. Glacial till and loess account for 24% and 21%, respectively, of the landslides. Alluvium is the soil associated with 13% of the slides and shale is the material in 7% of the slides. Figure 2.3 summarizes the soil type that is related to landslides.

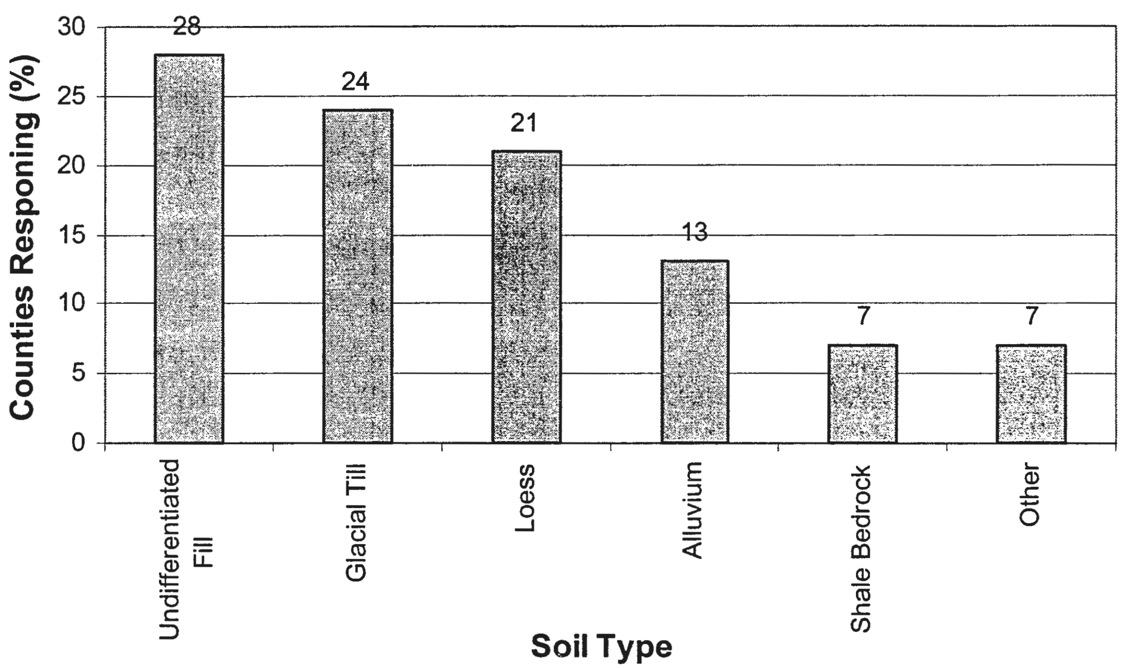


Figure 2.3 Occurence of Landslides in Various Soil Types

2.3 Location of the Landslides

One question in the survey asked if the slides occurred in foreslopes (embankments), backslopes (cuts), natural slopes, or along stream banks. Figure 2.4 shows the distribution of landslides. Foreslopes and backslopes were locations where stability problems are most frequent, with 37% and 32% of the slides in foreslopes and backslopes, respectively. In addition, 26% of the landslides occurred along streams or riverbanks and landslides in natural slopes comprised the remaining 5%. Most of the landslides in the northeastern and eastern part of Iowa occurred on backslopes; however most of the landslides in southeastern part of Iowa are in foreslopes.

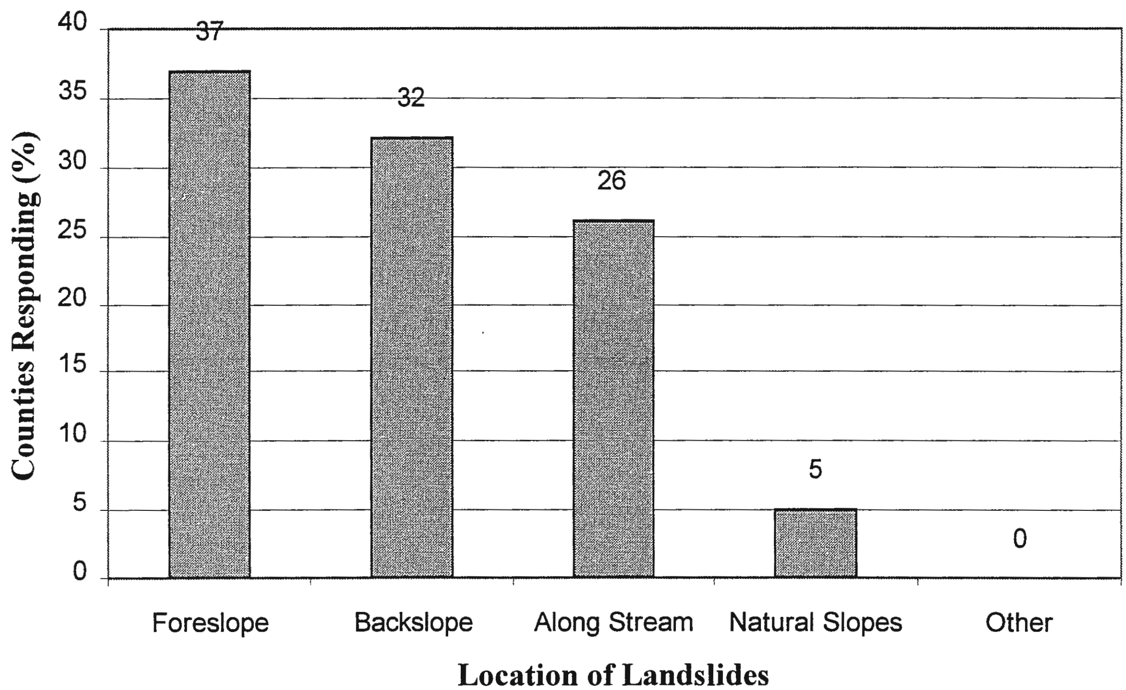


Figure 2.4 Location of Landslides

2.4 Probable Causes of Failures

All of the landslides occurred during spring and summer. Most, 78%, of the failures occurred in spring and the remaining 22% of the landslides happened in summer.

Fifty percent of the failures are associated with water where as 28% of the slope failures occurred after heavy rainfall and 22% are associated with high groundwater table conditions. Twenty one percent of the slope failures occurred due to design issues. In addition, maintenance or construction activities accounted for 14% of the stability problems while loading at the crest of slope and other causes account for 5% and 10%, respectively. These data are summarized in Figure 2.5.

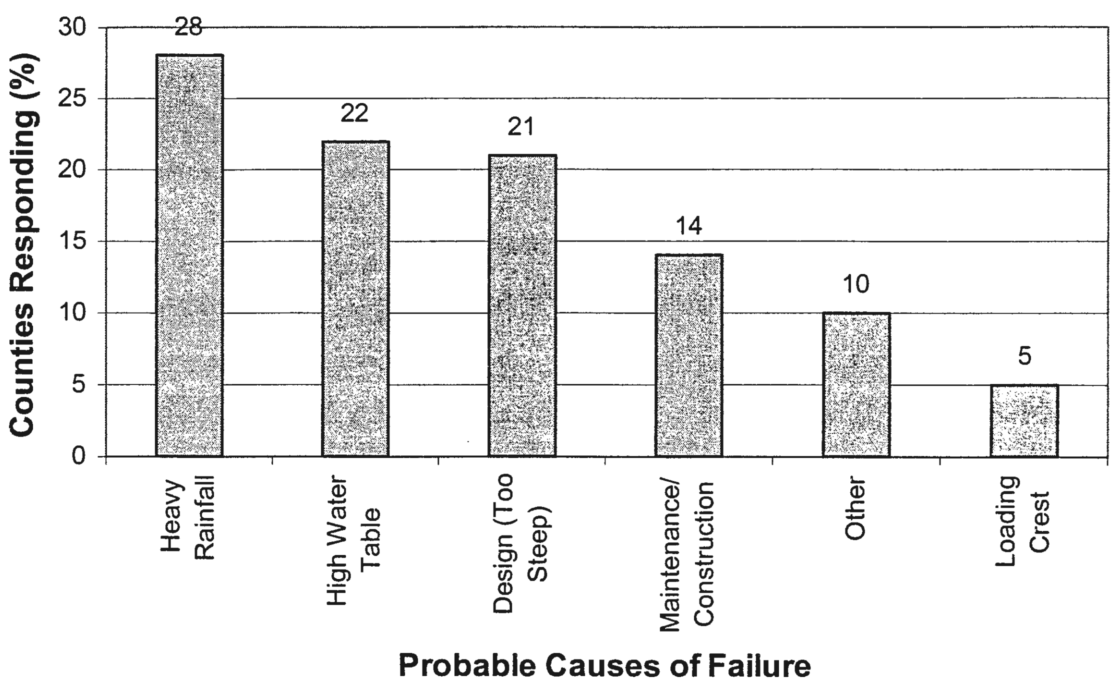


Figure 2.5 Probable Causes of Failure

2.5 Angles and Heights of Slopes before Failure

Ninety-six percent of the slopes were steeper than 3:1 before failure. Eighteen percent of the failures are steeper than 1:1, 49% are in between 1:1 and 2:1, 29% are between 2:1 and 3:1, 3% are between 3:1 and 4:1, and only 1% are flatter than 4:1. Figure 2.6 shows the frequency of slides versus the slope angle before failure. Nearly half, 41%, of the slopes were 11 ft. to 20 ft. high before failure. Twenty five percent, 25%, of the slopes were between 1 ft. and 10 ft. before failure, 21% and 13 % of the slopes were between 21 ft. and 30 ft. and greater than 30 ft., respectively. These data are shown in Figure 2.7.

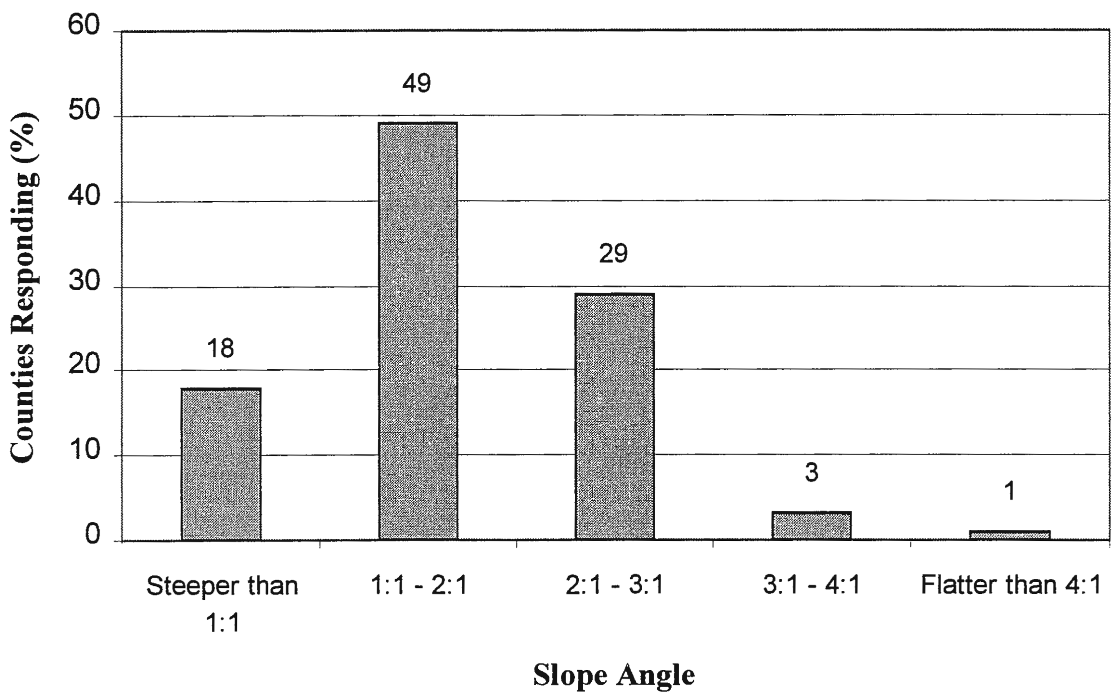


Figure 2.6 Slope Angle Before Failure

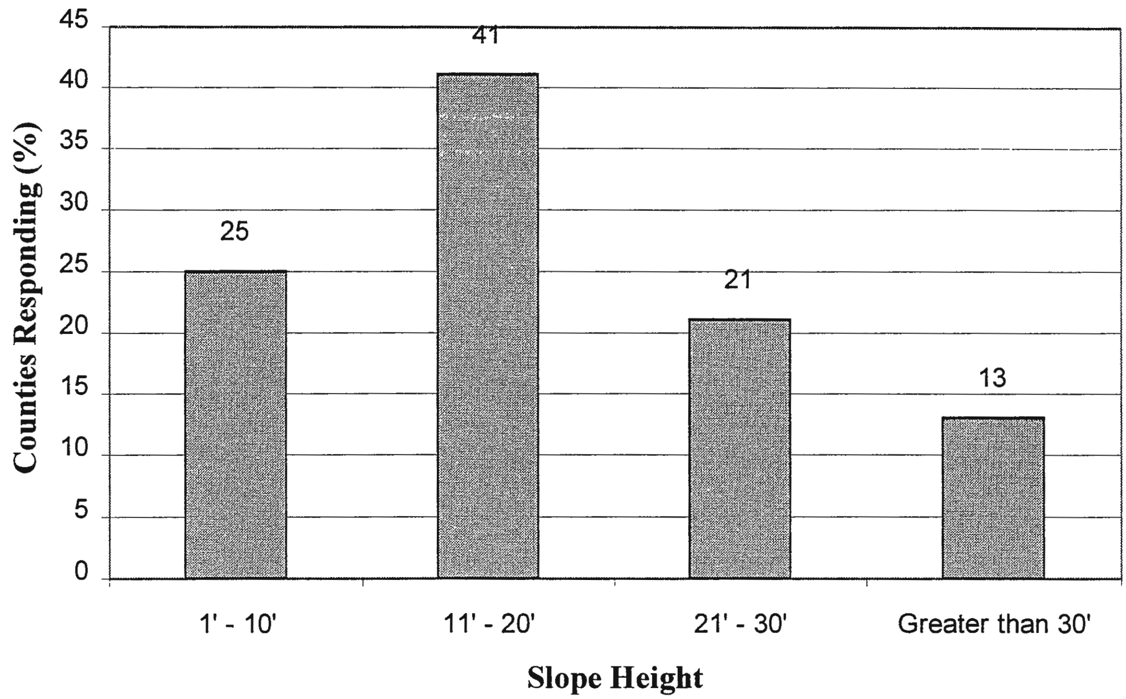


Figure 2.7 Height of Landslide

2.6 Methods Applied to Prevent and/or Repair Landslides

Several methods have been applied to prevent and/or repair landslides. The most common methods used were decreasing the slope angle, with 27%, and water control, with 26%. The next most frequent remedies used were loading the toe, with 13%, slope flattening by benching, with 12%, and structural support, with 8%. Geosynthetic stabilization, with 3%, was not used widely and chemical stabilization was not applied at all. In addition to the methods mentioned above, the county engineers have applied their own methods to deal with landslides; these made up 11%. The methods include using rip rap placement, sealing a utility trench cut at the top of the slope failure, and installing drainage tile near the toe of the slope failure. Figure 2.8 summarizes these data.

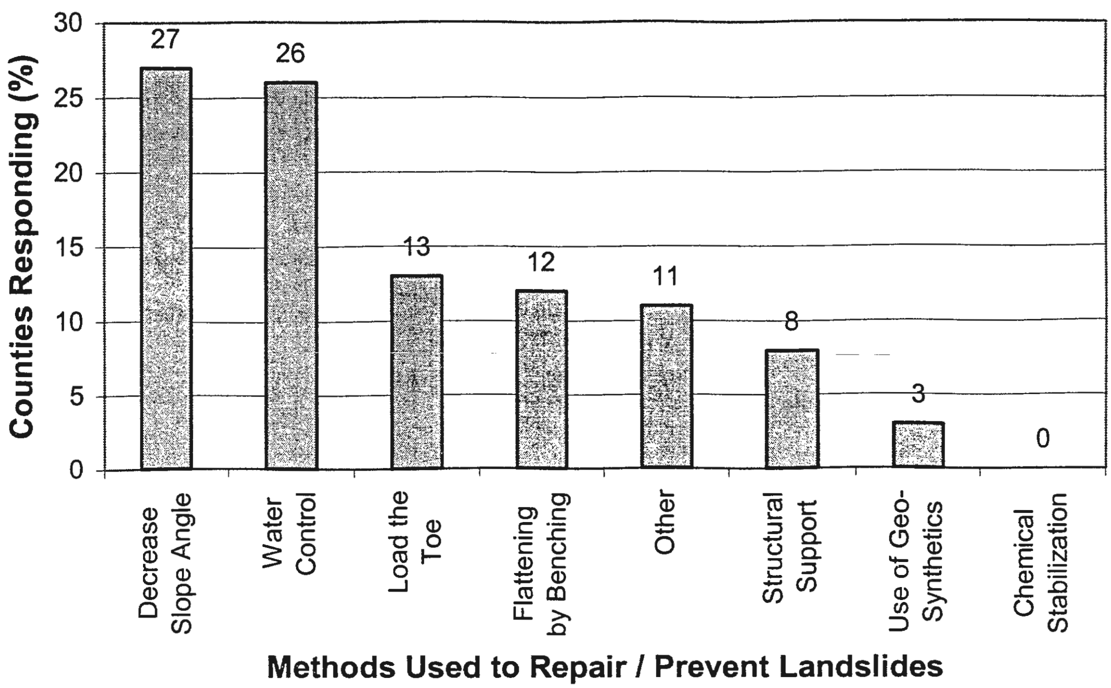


Figure 2.8 Methods Used to Repair / Prevent Landslides

2.7 Conclusions

Of the 60 counties that responded to the survey on landslides, 80% reported landslide activity and 31% of the counties had more than 11 landslides since 1993. On a statewide basis, most of the slides occured in foreslopes composed of undifferentiated fill. Both curvilinear and planar failure surfaces were observed throughout the state.

All of the landslides occurred during spring and summer with 50% of the failures caused by groundwater. Twenty one percent of the failures are associated with design issues. Nearly all of the slope failures occurred in slopes greater than 3:1 with the majority of failures on slopes between 1:1 and 2:1. Most of the slides occurred in slopes between 11 to 20 ft high before failure.

The most common and successful repair procedures have employed drainage and slope flattening. Structural support and geosynthetic stabilization are used very infrequently. Chemical stabilization has not been employed in the state.

CHAPTER 3. SHEAR STRENGTH DATA FROM IOWA DOT FILES

3.1 Objective

The objective of this task is to compile shear strength data that were available from Iowa DOT design plans. The purpose of compiling the data is to develop guidelines for stable slope angles and heights in different geologic materials found in Iowa.

3.2 Methodology

Iowa DOT projects from six counties were selected to obtain shear strength information representing different geologic materials encountered in Iowa. The exact locations of the borings were found from the DOT project reports. The boring locations were transferred to the appropriate USDA soil survey reports (Sherwood and Culver, 1977; Oelmann, 1984; Clark and McWilliams, 1978; Jury and Fisher, 1976; Worster, Harvey and Hanson, 1972; Lockridge, 1979; Koppen, 1975), and the geologic parent materials were interpreted. Statistical analyses were applied to the data to calculate means and standard deviations of cohesion intercept, dry unit weight, total unit weight, and moisture content. In addition, t-tests (Neville and Kennedy, 1964) at 5% and 10% levels of significance were carried out to determine if the differences in the mean values of the parameters for different geological materials are statistically significant. The friction angles reported (1 to 5 degrees) are very low for a consolidated, undrained (CU) test. These test results, therefore, are interpreted as an unconsolidated undrained (UU) response and the cohesion intercepts are interpreted as undrained shear strength (s_u) values.

3.3 Statistical Analysis Results

The results of the statistical analyses are presented in Tables 3.1 to 3.5. The results in Table 3.1 indicate that the standard deviations for cohesion, interpreted as undrained strength

Table 3.1. Summary of Triaxial Test Strength Data from Iowa DOT

English Unit

Geologic Material	Number of Data Set*	Cohesion (psf)		Dry Unit Weight (pcf)		Total Unit Weight (pcf)		Moisture Content (%)	
		Mean	St. Dev.	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev
Alluvium	96	624	412	94.6	7.7	120.8	7.0	28.1	2.5
Loess Derived Alluvium	8	674	375	92.0	4.4	117.9	4.4	28.0	5.6
Glacial Till	4	631	193	100.0	5.0	121.5	11.1	26.5	1.9
Friable Loess	8	456	145	90.6	4.9	115.8	6.9	27.8	5.1
Plastic Loess	47	657	384	92.7	8.1	119.0	8.7	28.4	5.2

SI Unit

Geologic Material	Number of Data Set*	Cohesion (kN/m^2)		Dry Unit Weight (kN/m^3)		Total Unit Weight (kN/m^3)		Moisture Content (%)	
		Mean	St. Dev.	Mean	St. Dev	Mean	St. Dev	Mean	St. Dev
Alluvium	96	29.9	19.8	14.9	1.2	19.0	1.1	28.1	2.5
Loess Derived Alluvium	8	32.3	18.0	14.5	0.7	18.6	0.7	28.0	5.6
Glacial Till	4	30.3	9.3	15.7	0.8	19.1	1.7	26.5	1.9
Friable Loess	8	21.9	7.0	14.3	0.8	18.2	1.1	27.8	5.1
Plastic Loess	47	31.5	18.4	14.6	1.3	18.7	1.4	28.4	5.2

* A data set represents a number of triaxial tests that were carried out in order to obtain the cohesion value.

(s_u), are high, indicating a high degree of variability in these data. The mean and standard deviation results indicate a significant amount of overlap of parameter values between the different geological materials. This is confirmed by the t-test results in Tables 3.2 to 3.5. The only results showing a significant difference across the different geologic parent materials are total unit weight between alluvium and friable loess, dry unit weight between loess derived alluvium and glacial till, and between glacial till and friable loess.

3.4 Summary

A statistical analysis, t-test, was carried out to determine if the differences in shear strength and unit weight between different geological materials are statistically significant. A significant difference exists for total unit weight between alluvium and friable loess, dry unit weight between loess derived alluvium and glacial till, and between glacial till and friable loess.

Table 3.2 Cohesion (kN/m^2)

Type of Soils	No. of sample	Standard Deviation	Mean	t	Degree of Freedom	Conclusion (@ 5 percent level of significance)	(@ 10percent level of significance)
Alluvium	96	19.8	29.9	0.32	102	No significant difference	No significant difference
Loess Derived Alluvium	8	18.0	32.3				
Alluvium	96	19.8	29.9	0.04	98	No significant difference	No significant difference
Glacial Till	4	9.3	30.3				
Alluvium	96	19.8	29.9	1.14	102	No significant difference	No significant difference
Friable Loess	8	7.0	21.9				
Alluvium	96	19.8	29.9	0.46	141	No significant difference	No significant difference
Plastic Loess	47	18.4	31.5				
Loess Derived Alluvium	8	18.0	32.3	0.20	10	No significant difference	No significant difference
Glacial Till	4	9.3	30.3				
Loess Derived Alluvium	8	18.0	32.3	1.52	14	No significant difference	No significant difference
Friable Loess	8	7.0	21.9				
Loess Derived Alluvium	8	18.0	32.3	0.11	53	No significant difference	No significant difference
Plastic Loess	47	18.4	31.5				
Glacial Till	4	9.3	30.3	1.77	10	No significant difference	No significant difference
Friable Loess	8	7.0	21.9				
Glacial Till	4	9.3	30.3	0.13	49	No significant difference	No significant difference
Plastic Loess	47	18.4	31.5				
Friable Loess	8	7.0	21.9	1.45	53	No significant difference	No significant difference
Plastic Loess	47	18.4	31.5				

Table 3.3 Dry Unit Weight (kN/m^3)

Type of Soils	No. of sample	Standard Deviation	Mean	t	Degree of Freedom	Conclusion (@ 5 percent level of significance)	(@ 10percent level of significance)
Alluvium Loess Derived Alluvium	96 8	1.2 0.7	14.9 14.5	0.93	102	No significant difference	No significant difference
Alluvium Glacial Till	96 4	1.2 0.8	14.9 15.7	1.32	98	No significant difference	No significant difference
Alluvium Friable Loess	96 8	1.2 0.8	14.9 14.3	1.48	102	No significant difference	No significant difference
Alluvium Plastic Loess	96 47	1.2 1.3	14.9 14.6	1.37	141	No significant difference	No significant difference
Loess Derived Alluvium Glacial Till	8 4	0.7 0.8	14.5 15.7	2.68	10	A significant difference	A significant difference
Loess Derived Alluvium Friable Loess	8 8	0.7 0.8	14.5 14.3	0.65	14	No significant difference	No significant difference
Loess Derived Alluvium Plastic Loess	8 47	0.7 1.3	14.5 14.6	0.21	53	No significant difference	No significant difference
Glacial Till Friable Loess	4 8	0.8 0.8	15.7 14.3	3.02	10	A significant difference	A significant difference
Glacial Till Plastic Loess	4 47	0.8 1.3	15.7 14.6	1.66	49	No significant difference	No significant difference
Friable Loess Plastic Loess	8 47	0.8 1.3	14.3 14.6	0.72	53	No significant difference	No significant difference

Table 3.4 Total Unit Weight (kN/m^3)

Type of Soils	No. of sample	Standard Deviation	Mean	t	Degree of Freedom	Conclusion (@ 5 percent level of significance)	(@ 10percent level of significance)
Alluvium Loess Derived Alluvium	96 8	1.1 0.7	19.0 18.6	1.01	102	No significant difference	No significant difference
Alluvium Glacial Till	96 4	1.1 1.7	19.0 19.1	0.17	98	No significant difference	No significant difference
Alluvium Friable Loess	96 8	1.1 1.1	19.0 18.2	1.95	102	No significant difference	A significant difference
Alluvium Plastic Loess	96 47	1.1 1.4	19.0 18.7	1.40	141	No significant difference	No significant difference
Loess Derived Alluvium Glacial Till	8 4	0.7 1.7	18.6 19.1	0.74	10	No significant difference	No significant difference
Loess Derived Alluvium Friable Loess	8 8	0.7 1.1	18.6 18.2	0.85	14	No significant difference	No significant difference
Loess Derived Alluvium Plastic Loess	8 47	0.7 1.4	18.6 18.7	0.20	53	No significant difference	No significant difference
Glacial Till Friable Loess	4 8	1.7 1.1	19.1 18.2	1.12	10	No significant difference	No significant difference
Glacial Till Plastic Loess	4 47	1.7 1.4	19.1 18.7	0.54	49	No significant difference	No significant difference
Friable Loess Plastic Loess	8 47	1.1 1.4	18.2 18.7	0.94	53	No significant difference	No significant difference

Table 3.5 Moisture Content (%)

Type of Soils	No. of sample	Standard Deviation	Mean	t	Degree of Freedom	Conclusion (@ 5 percent level of significance)	(@ 10percent level of significance)
Alluvium Loess Derived Alluvium	96 8	2.5 5.6	28.1 28.0	0.14	102	No significant difference	No significant difference
Alluvium Glacial Till	96 4	2.5 1.9	28.1 26.5	1.27	98	No significant difference	No significant difference
Alluvium Friable Loess	96 8	2.5 5.1	28.1 27.8	0.37	102	No significant difference	No significant difference
Alluvium Plastic Loess	96 47	2.5 5.2	28.1 28.4	0.39	141	No significant difference	No significant difference
Loess Derived Alluvium Glacial Till	8 4	5.6 1.9	28.0 26.5	0.50	10	No significant difference	No significant difference
Loess Derived Alluvium Friable Loess	8 8	5.6 5.1	28.0 27.8	0.09	14	No significant difference	No significant difference
Loess Derived Alluvium Plastic Loess	8 47	5.6 5.2	28.0 28.4	0.20	53	No significant difference	No significant difference
Glacial Till Friable Loess	4 8	1.9 5.1	26.5 27.8	0.47	10	No significant difference	No significant difference
Glacial Till Plastic Loess	4 47	1.9 5.2	26.5 28.4	0.72	49	No significant difference	No significant difference
Friable Loess Plastic Loess	8 47	5.1 5.2	27.8 28.4	0.32	53	No significant difference	No significant difference

CHAPTER 4. SHEAR STRENGTH DATA FROM ENGINEERING CONSULTANTS AND LITERATURE REVIEW

4.1 Objective

The objective of this task is to compile effective stress shear strength data provided by engineering consultants and from a literature review. The purpose of compiling the data is to develop guidelines for stable slope angles and heights in different geologic materials found in Iowa.

4.2 Methodology

Triaxial test data were provided by two consulting engineering companies, Terracon and CH2M HILL. Geologic parent materials for the Terracon data were interpreted by comparing the sample location, depth and description from Terracon's boring reports with a surficial geologic map (Ruhe, 1969). CH2M HILL provided an interpretation of geologic parent material for their samples. The tests reported by Olson (1958) and Benak (1967) were carried out on friable loess. The data were sorted according to geologic parent materials, and statistics were used to calculate the mean and standard deviation of cohesion intercept, friction angle, dry unit weight, total unit weight and moisture content. These data are shown in Table 4.1. In addition, t-tests (Neville and Kennedy, 1964) at 5% and 10% levels of significant difference were carried out to determine if the differences in parameter means between various geological materials are statistically significant.

4.3 Statistical Analysis Results

The results of the statistical analyses are presented in Tables 4.2 to 4.6. The data in Table 4.2 show that the standard deviations for cohesion are high which indicates a high degree of scatter in this parameters. In the same table, the results show a significant statistical

Table 4.1 Summary of Strength and Unit Weight Data from Engineering Consultants and Literature Review

English Unit

Geologic Material	Number of Data Set*	Cohesion (psf)	Friction Angle (degree)	Dry Unit Weigh (pcf)	Total Unit Weight (pcf)	Moisture Content (%)
		Mean	Mean	Mean	Mean	Mean
Alluvium	4	48	31	97.6	121.8	24.80
Glacial Till	12	159	28	95.9**	121.6**	27.70
Plastic Loess	21	144	29	91.0	119.0	31.20
Friable Loess	10	109	25	85.7	114.5	33.25

SI Unit

Geologic Material	Number of Data Set*	Cohesion (kN/m^2)	Friction Angle (degree)	Dry Unit Weight (kN/m^3)	Total Unit Weight (kN/m^3)	Moisture Content (%)
		Mean	Mean	Mean	Mean	Mean
Alluvium	4	2.28	31	15.3	19.1	24.80
Glacial Till	12	7.65	28	15.1	19.1	27.70
Plastic Loess	21	6.91	29	14.3	18.7	31.20
Friable Loess	10	5.21	25	13.5	18.0	33.25

Notes: The dry unit weight, total unit weight and moisture content of Friable loess are from Terracon (2 samples)

* A data set represents three triaxial tests that were carried out in order to obtain the strength data

** The unit weight of glaciall till is considerably low

Table 4.2 Cohesion (kN/m^2)

Type of Soils	No. of Sample	Mean	Standard Deviation	t	Degree of Freedom	Conclusion	
						5 percent level of significance	(@ 10percent level of significance)
Alluvium Glacial Till	4 12	2 8	2 6	1.85	14	No significant difference	A significant difference
Alluvium Plastic Loess	4 21	2 7	2 4	2.14	23	A significant difference	A significant difference
Glacial Till Plastic Loess	12 21	8 7	6 4	8.43	31	A significant difference	A significant difference
Friable Loess Plastic Loess	10 21	5 7	4 4	1.09	29	No significant difference	No significant difference
Friable Loess Alluvium	10 4	5 2	4 2	1.47	12	No significant difference	No significant difference
Friable Loess Glacial till	10 12	5 8	4 6	1.18	20	No significant difference	No significant difference

Table 4.3 Friction Angle (degree)

Type of Soils	No. of Sample	Mean	Standard Deviation	t	Degree of Freedom	Conclusion	
						5 percent level of significance	(@ 10percent level of significance)
Alluvium Glacial Till	4 12	31 28	1 3	1.55	14	No significant difference	No significant difference
Alluvium Plastic Loess	4 21	31 29	1 4	0.99	23	No significant difference	No significant difference
Glacial Till Plastic Loess	12 21	28 29	3 4	5.72	31	A significant difference	A significant difference
Friable Loess Plastic Loess	10 21	25 29	2 4	2.29	29	A significant difference	A significant difference
Friable Loess Alluvium	10 4	25 31	2 1	5.50	12	A significant difference	A significant difference
Friable Loess Glacial till	10 12	25 28	2 3	2.30	20	A significant difference	A significant difference

Table 4.4 Dry Unit Weight (kN/m^2)

Type of Soils	No. of Sample	Mean	Standard Deviation	t	Degree of Freedom	Conclusion: 5 percent level of significance	(@ 10percent level of significance)
Alluvium	4	15	1	0.25	14	No significant difference	No significant difference
Glacial Till	12	15	2				
Alluvium	4	15	1	1.67	23	No significant difference	No significant difference
Plastic Loess	21	14	1				
Glacial Till	12	15	2	1.38	31	No significant difference	No significant difference
Plastic Loess	21	14	1				
Friable Loess	2	13	0	0.97	21	No significant difference	No significant difference
Plastic Loess	21	14	1				
Friable Loess	2	13	0	3.40	4	A significant difference	A significant difference
Alluvium	4	15	1				
Friable Loess	2	13	0	1.08	12	No significant difference	No significant difference
Glacial till	12	15	2				

Table 4.5 Total Unit Weight (kN/m^2)

Type of Soils	No. of Sample	Mean	Standard Deviation	t	Degree of Freedom	Conclusion: 5 percent level of significance	(@ 10percent level of significance)
Alluvium	4	19	1	0.04	14	No significant difference	No significant difference
Glacial Till	12	19	1				
Alluvium	4	19	1	1.06	23	No significant difference	No significant difference
Plastic Loess	21	19	1				
Glacial Till	12	19	1	9.83	31	A significant difference	A significant difference
Plastic Loess	21	19	1				
Friable Loess	2	18	0	1.28	21	No significant difference	No significant difference
Plastic Loess	21	19	1				
Friable Loess	2	18	0	2.28	4	No significant difference	A significant difference
Alluvium	4	19	1				
Friable Loess	2	18	0	1.16	12	No significant difference	No significant difference
Glacial till	12	19	1				

Table 4.6 Moisture Content (%)

Type of Soils	No. of Sample	Mean	Standard Deviation	t	Degree of Freedom	Conclusion	
						5 percent level of significance(@	10percent level of significance)
Alluvium Glacial Till	4 12	25 28	2 7	0.75	14	No significant difference	No significant difference
Alluvium Plastic Loess	4 21	25 31	2 5	2.33	23	A significant difference	A significant difference
Glacial Till Plastic Loess	12 21	28 31	7 5	1.56	31	No significant difference	No significant difference
Friable Loess Plastic Loess	2 21	33 31	1 5	0.53	21	No significant difference	No significant difference
Friable Loess Alluvium	2 4	33 25	1 2	5.36	4	A significant difference	A significant difference
Friable Loess Glacial till	2 12	33 28	1 7	1.01	12	No significant difference	No significant difference

difference for cohesion intercept between alluvium and glacial till, between alluvium and plastic loess, and between glacial till and plastic loess. A significant difference exists for friction angle between glacial till and plastic loess, between friable loess and plastic loess, between friable loess and alluvium, and between friable loess and glacial till (see Table 4.3). The only significant difference for dry unit weight in Table 4.4 is between friable loess and alluvium. There are significant differences between glacial till and plastic loess, and between friable loess and alluvium for total unit weight (see Table 4.5). As shown in Table 4.6, a significant difference of moisture content can be found between alluvium and plastic loess, and also between friable loess and alluvium.

4.4 Discussion

Two kinds of triaxial test data were used in this analysis; consolidated, undrained (CU) data with pore pressure measurement from the consultants and consolidated, drained (CD) data from Olson (1958) and Benak (1967). The cohesion intercepts and friction angles of these data compare well with results from similar tests on similar materials, as shown on Table 4.7, from the current research.

Table 4.7 Comparison of Friable Loess Shear Strength Data

	Cohesion (psf)	Friction Angle (degree)
Current Research	136	29
Literature Review and Consultants	109	25

CHAPTER 5. STABLE SLOPE GUIDELINES

5.1 Objective

The objective of this section is to provide guidance on stable slope angles and slope heights for different geological materials encountered in Iowa. The curves presented are not for design but only for preliminary evaluation of stable slope angles and heights.

5.2 Methodology

Two analyses were selected to calculate the relationship between stable slope angle and slope height. The Taylor (1948) analysis was used for an unconsolidated undrained condition and the Culmann analysis (Spangler, 1960) was selected to represent the slope in a drained condition

5.2.1 Taylor Analysis

The Taylor analysis was used to analyze the stability of slopes immediately after construction, before pore pressure equalization and establishment of steady state seepage conditions.

In this case, the Taylor analysis was used assuming that the failure surface is a circular arc that passes through the toe of slope (i.e. D = 1), and that the factor safety = 1. Undrained strength parameters interpreted from the DOT files were used in this analysis. The Taylor (1948) Stability Number Chart (Lambe and Whitman, 1969), shown in Figure 5.1, that gives stability number directly for any given value of slope angle, was used to obtain the stable slope height. A mean value of undrained strength (s_u) and total unit weight (γ_t) were used for each geologic material and 10 degrees was selected as a lower bound for the slope angle. From the graph where D = 1, stability numbers, $\frac{s_u}{\gamma_t H}$, were determined for slope

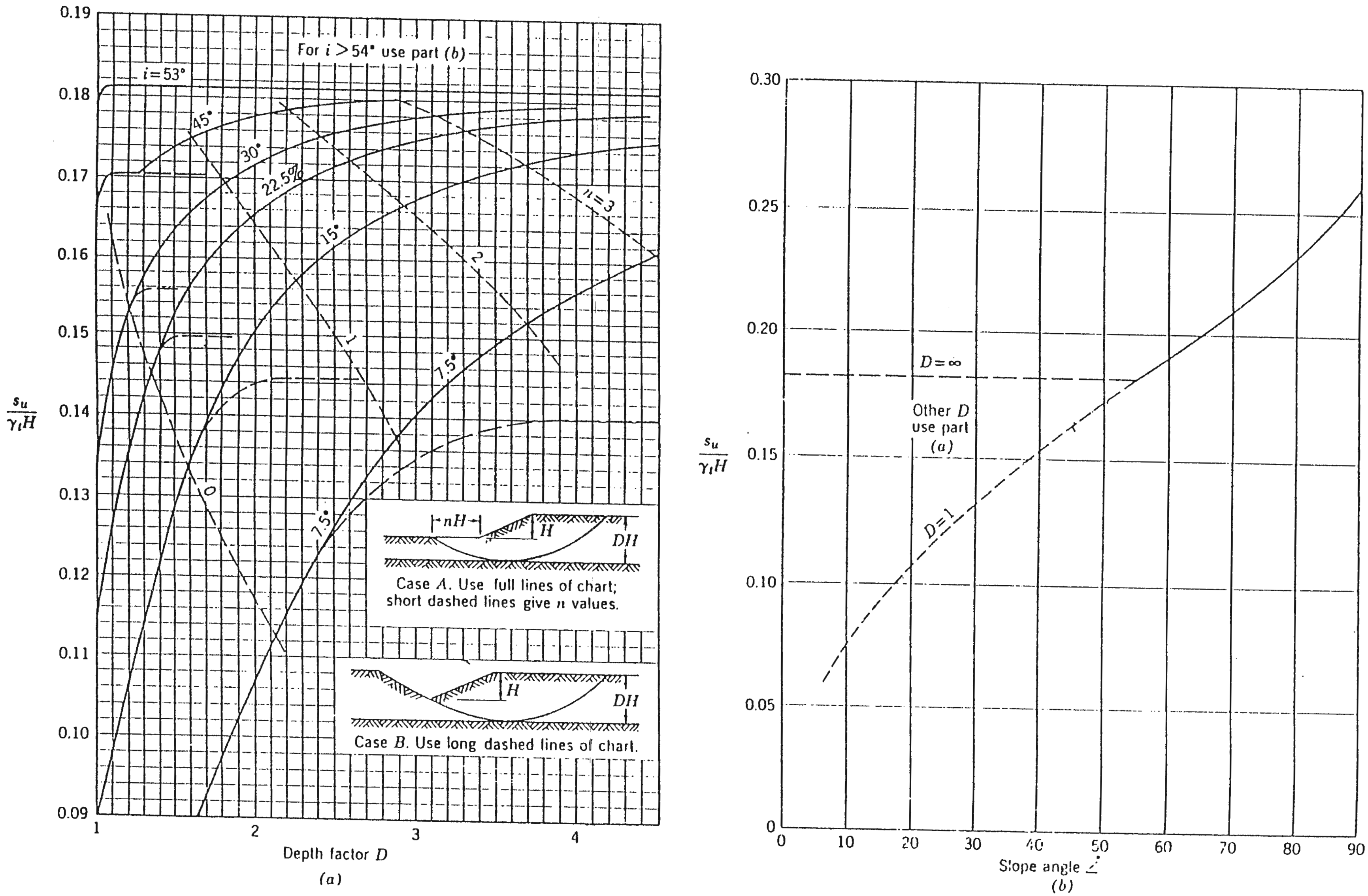


Figure 5.1 Stability Charts for $\phi = 0$ (From Taylor, 1948)

angles of 10, 14 (4:1), 18.4 (3:1), 26.5 (2:1), 30, 45 (1:1), 50, 60, 70 and 90 degrees. For different geologic materials, the s_u and γ_t values are known and stable height (H) can be determined.

A sample calculation for alluvium is shown below:

$s_u = 29.91$ kN/m^2

$\gamma_t = 18.99$ kN/m^3

By referring to the curve D = 1 for a 90° slope angle:

$$\frac{s_u}{\gamma_t H} = 0.26$$

Therefore,

$$\frac{29.91}{18.99(H)} = 0.26 \qquad \Rightarrow \; H \approx 6 \text{ meters}$$

This calculation is then repeated for a variety of slope angles to generate a curve of slope height (H) versus slope angle (i).

5.2.2 Culmann Analysis

Culmann analysis was used to represent the slopes in a drained condition; the analysis is in terms of effective stresses. Pore pressures are not included in the Culmann analysis. It is a solution based upon the assumption that the failure surface is a plane passing through the toe of the slope. Field observations show that this assumption is approximately valid for high angle slopes, whereas lower-angle slopes tend to fail along a circular arc or a logarithmic spiral (Taylor 1948).

The equation

$$H = \frac{4\, c\; Sin\, i\; Cos\phi}{\gamma_t (1 - Cos(i - \phi))}$$

was used to calculate the maximum stable slope height where, H = maximum stable slope height, c = cohesion intercept of the soil, i = slope angle, ϕ = internal friction angle, and γ_t = total unit weight of soil.

Mean effective stress strength parameters from the consultants and literature review were used in the Culmann analysis.

A sample calculation for alluvium is shown below:

$c = 2.28\ kN/m^2$

$i = 90$ degrees

$\phi = 30.7$ degrees

$\gamma_t = 19.15\ kN/m^3$

Therefore:

$$H = \frac{4(2.28)(Sin90)(Cos30.7)}{19.15(1-(Cos(90-30.7))}$$

=> H $\approx$ 1 meters

The calculation is then repeated for various slope angles to generate curves of slope height (H) versus slope angle (i) for each geologic material.

5.3 Results

The results for the Taylor analysis are included in Table 5.1 and for the Culmann analysis in Table 5.2. The results are applicable to cut slopes (backslopes) and not compacted slopes (foreslopes) as the shear strength data used on these analyses were determined from relatively undisturbed Shelby tube samples and not from recompacted soil samples. No factors of safety are applied to the results and pore pressures are not included in the Culmann analysis. Combinations of slope height and slope angle below both of the curves (Figure 5.2 to 5.6) represent stable conditions while those above one of the curves represent instability.

Table 5.1 Taylor Analysis (Undrained, DOT data)

Alluvium
Total Sample = 96
Mean of cohesion (kN/m^2) = 29.91
Mean of total Unit Weight (kN/m^3) = 18.99

Slope Angle (Degree)	Stability #	Cohesion/Total Unit Weight	H (Meter)
90	0.26	1.58	6.06
70	0.21	1.58	7.50
60	0.19	1.58	8.29
50	0.17	1.58	9.13
45 (1:1)	0.16	1.58	9.69
30	0.13	1.58	11.89
26.5 (2:1)	0.12	1.58	12.86
18.4 (3:1)	0.10	1.58	15.75
14 (4:1)	0.09	1.58	18.00
10	0.08	1.58	21.00

Loess Derived Alluvium
Total Sample = 8
Mean of cohesion (kN/m^2) = 32.29
Mean of total Unit Weight (kN/m^3) = 18.53

Slope Angle (Degree)	Stability #	Cohesion/Total Unit Weight	H (Meter)
90	0.26	1.74	6.70
70	0.21	1.74	8.30
60	0.19	1.74	9.17
50	0.17	1.74	10.10
45 (1:1)	0.16	1.74	10.72
30	0.13	1.74	13.15
26.5 (2:1)	0.12	1.74	14.23
18.4 (3:1)	0.10	1.74	17.43
14 (4:1)	0.09	1.74	19.92
10	0.08	1.74	23.23

Glacial Till
Total Sample = 4
Mean of cohesion (kN/m^2) = 30.22
Mean of total Unit Weight (kN/m^3) = 19.10

Slope Angle (Degree)	Stability #	Cohesion/Total Unit Weight	H (Meter)
90	0.26	1.58	6.09
70	0.21	1.58	7.54
60	0.19	1.58	8.33
50	0.17	1.58	9.17
45 (1:1)	0.16	1.58	9.74
30	0.13	1.58	11.94
26.5 (2:1)	0.12	1.58	12.92
18.4 (3:1)	0.10	1.58	15.82
14 (4:1)	0.09	1.58	18.08
10	0.08	1.58	21.10

Table 5.1 (continued)

Friable Loess
Total Sample = 8
Mean of cohesion (kN/m^2) = 21.85
Mean of total Unit Weight (kN/m^3) = 18.20

Slope Angle (Degree)	Stability #	Cohesion/Total Unit Weight	H (Meter)
90	0.26	1.20	4.62
70	0.21	1.20	5.72
60	0.19	1.20	6.32
50	0.17	1.20	6.96
45 (1:1)	0.16	1.20	7.39
30	0.13	1.20	9.06
26.5 (2:1)	0.12	1.20	9.80
18.4 (3:1)	0.10	1.20	12.00
14 (4:1)	0.09	1.20	13.72
10	0.08	1.20	16.00

Plastic Loess
Total Sample = 47
Mean of cohesion (kN/m^2) = 31.45
Mean of total Unit Weight (kN/m^3) = 18.70

Slope Angle (Degree)	Stability #	Cohesion/Total Unit Weight	H (Meter)
90	0.26	1.68	6.47
70	0.21	1.68	8.01
60	0.19	1.68	8.85
50	0.17	1.68	9.75
45 (1:1)	0.16	1.68	10.35
30	0.13	1.68	12.69
26.5 (2:1)	0.12	1.68	13.73
18.4 (3:1)	0.10	1.68	16.82
14 (4:1)	0.09	1.68	19.22
10	0.08	1.68	22.42

Table 5.2 Culmann Analysis (Consolidated Drained, from Literature Review and Consultants)

Alluvium
Number of Sample = 4

Internal Friction (degree)	Total Unit Weight (lb/ft^3)	Slope Angle, I (degree)	Cohesion (PSF)	Maximum Height, H (ft)	Maximum Height, H (Meter)
30.7	121.8	90	47.52	2.74	0.84
30.7	121.8	70	47.52	5.58	1.70
30.7	121.8	60	47.52	9.08	2.77
30.7	121.8	50	47.52	18.29	5.58
30.7	121.8	45	47.52	30.62	9.33
30.7	121.8	30	47.52	8990.16	2740.20
30.7	121.8	26.5	47.52	222.95	67.96
30.7	121.8	18.4	47.52	18.45	5.62
30.7	121.8	14	47.52	7.70	2.35
30.7	121.8	10	47.52	3.61	1.10

Glacial Till
Number of Sample = 12

Internal Friction (degree)	Total Unit Weight (lb/ft^3)	Slope Angle, I (degree)	Cohesion (PSF)	Maximum Height, H (ft)	Maximum Height, H (Meter)
28.1	121.6	90	159.4	8.74	2.67
28.1	121.6	70	159.4	17.00	5.18
28.1	121.6	60	159.4	26.52	8.08
28.1	121.6	50	159.4	49.10	14.97
28.1	121.6	45	159.4	75.73	23.08
28.1	121.6	30	159.4	4206.53	1282.15
28.1	121.6	26.5	159.4	5293.42	1613.44
28.1	121.6	18.4	159.4	102.12	31.13
28.1	121.6	14	159.4	37.14	11.32
28.1	121.6	10	159.4	16.23	4.95

Table 5.2 (continued)

Friable Loess

Number of Sample = 10

Internal Friction (degree)	Total Unit Weight* (lb/ft^3)	Slope Angle, I (degree)	Cohesion (PSF)	Maximum Height, H (ft)	Maximum Height, H (Meter)
25.5	98.54	90	109	6.98	2.13
25.5	98.54	70	109	13.02	3.97
25.5	98.54	60	109	19.55	5.96
25.5	98.54	50	109	33.75	10.29
25.5	98.54	45	109	48.86	14.89
25.5	98.54	30	109	634.12	193.28
25.5	98.54	26.5	109	10778.59	3285.31
25.5	98.54	18.4	109	165.67	50.50
25.5	98.54	14	109	48.29	14.72
25.5	98.54	10	109	19.10	5.82

* Due to the limited information from consultants and literature review, total unit weight value from current research was used

Plastic Loess

Number of Sample = 21

Internal Friction (degree)	Total Unit Weight (lb/ft^3)	Slope Angle, I (degree)	Cohesion (PSF)	Maximum Height, H (ft)	Maximum Height, H (Meter)
28.6	119	90	144	8.15	2.48
28.6	119	70	144	15.98	4.87
28.6	119	60	144	25.13	7.66
28.6	119	50	144	47.22	14.39
28.6	119	45	144	73.86	22.51
28.6	119	30	144	7118.24	2169.64
28.6	119	26.5	144	2823.41	860.58
28.6	119	18.4	144	84.88	25.87
28.6	119	14	144	31.84	9.70
28.6	119	10	144	14.13	4.31

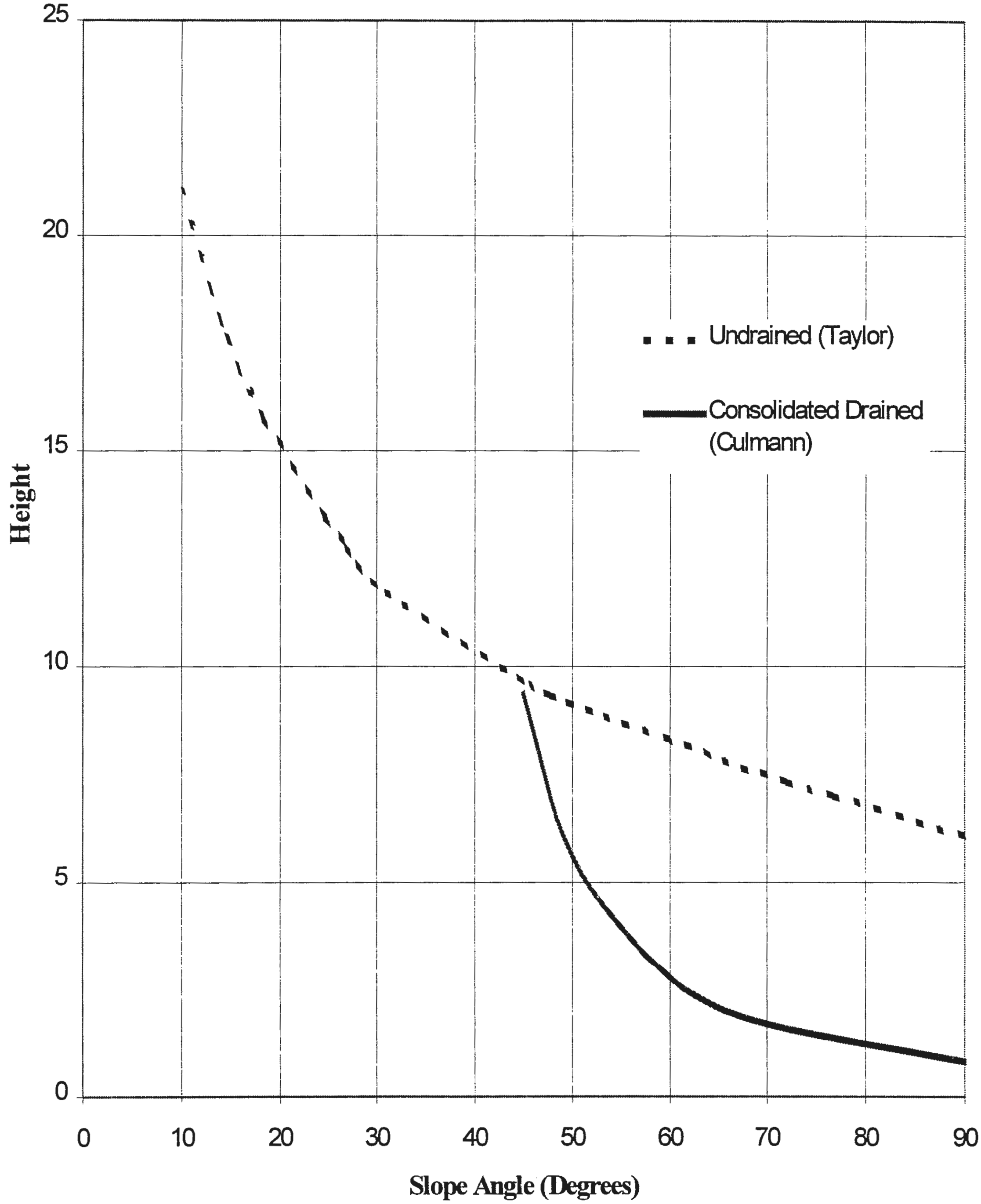


Figure 5.2 Alluvium

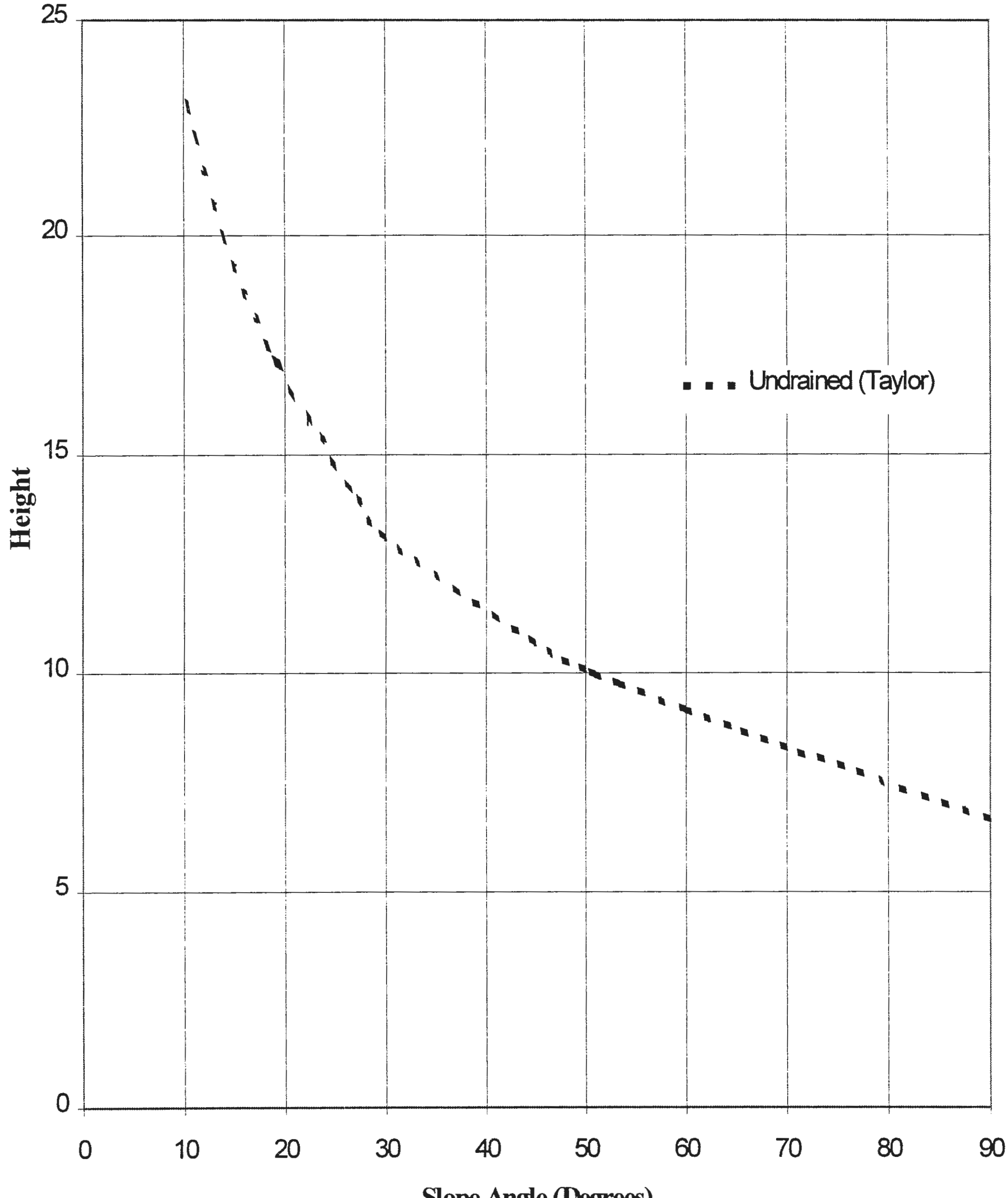


Figure 5.3 Loess Derived Alluvium

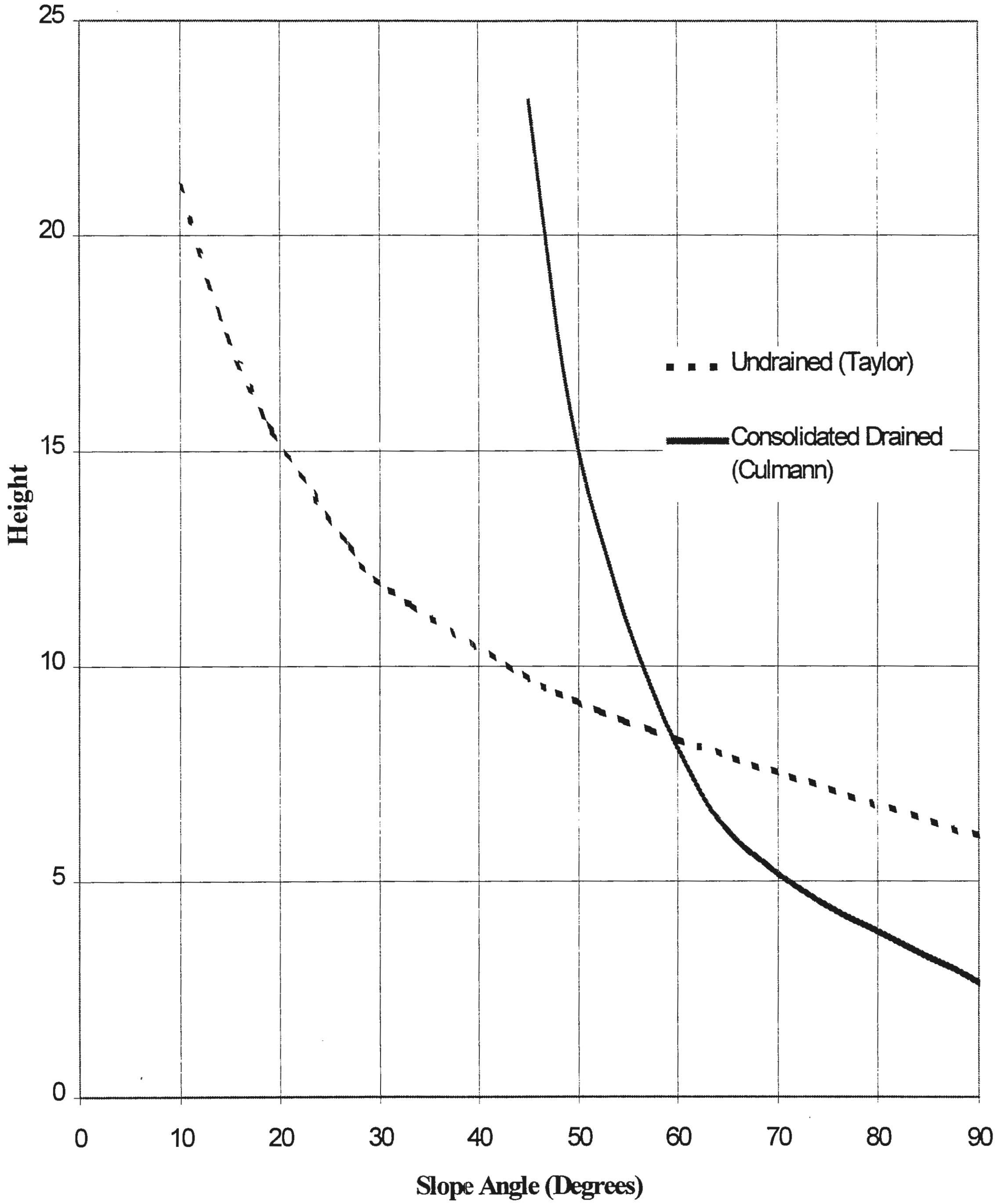


Figure 5.4 Glacial Till

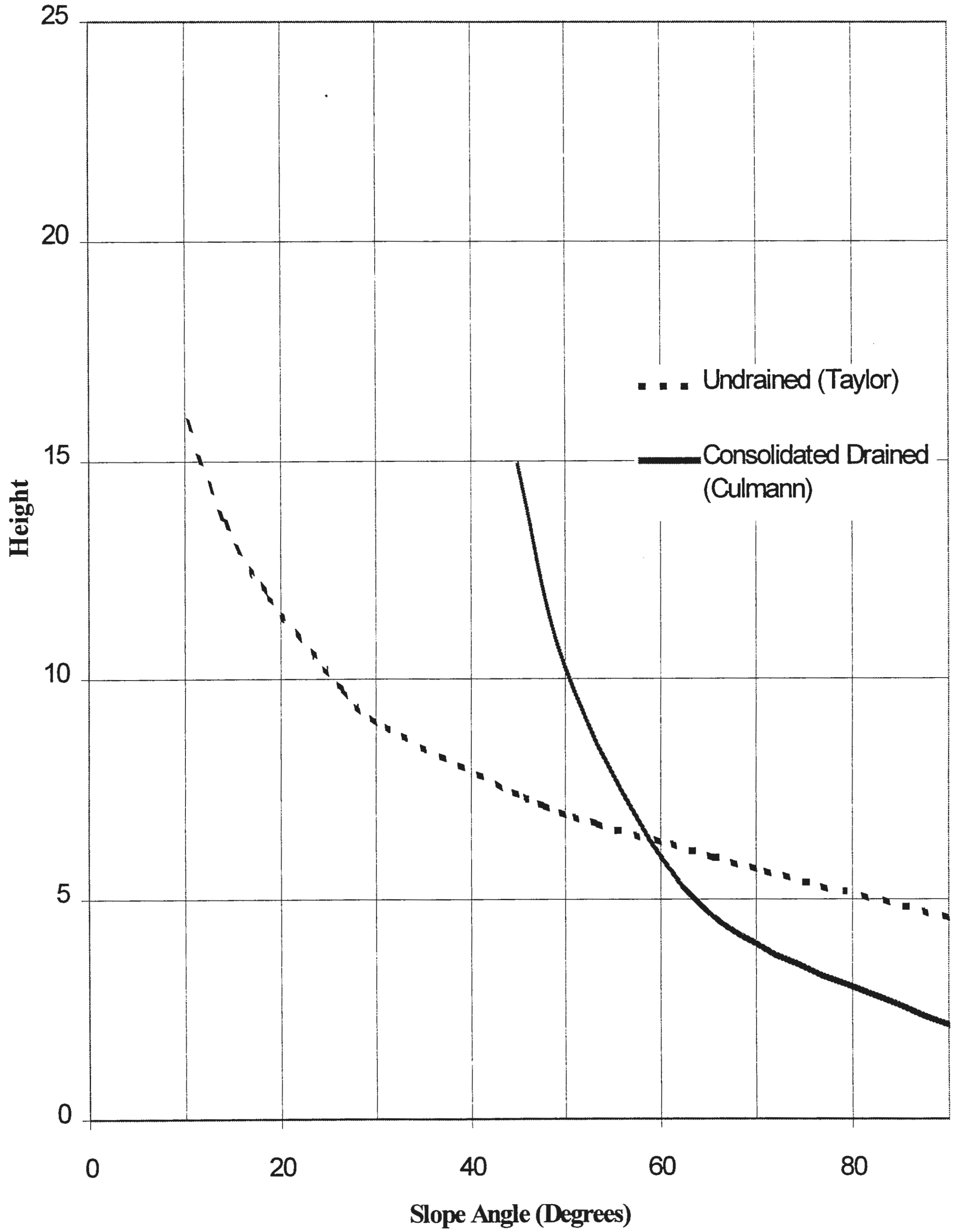


Figure 5.5 Friable Loess

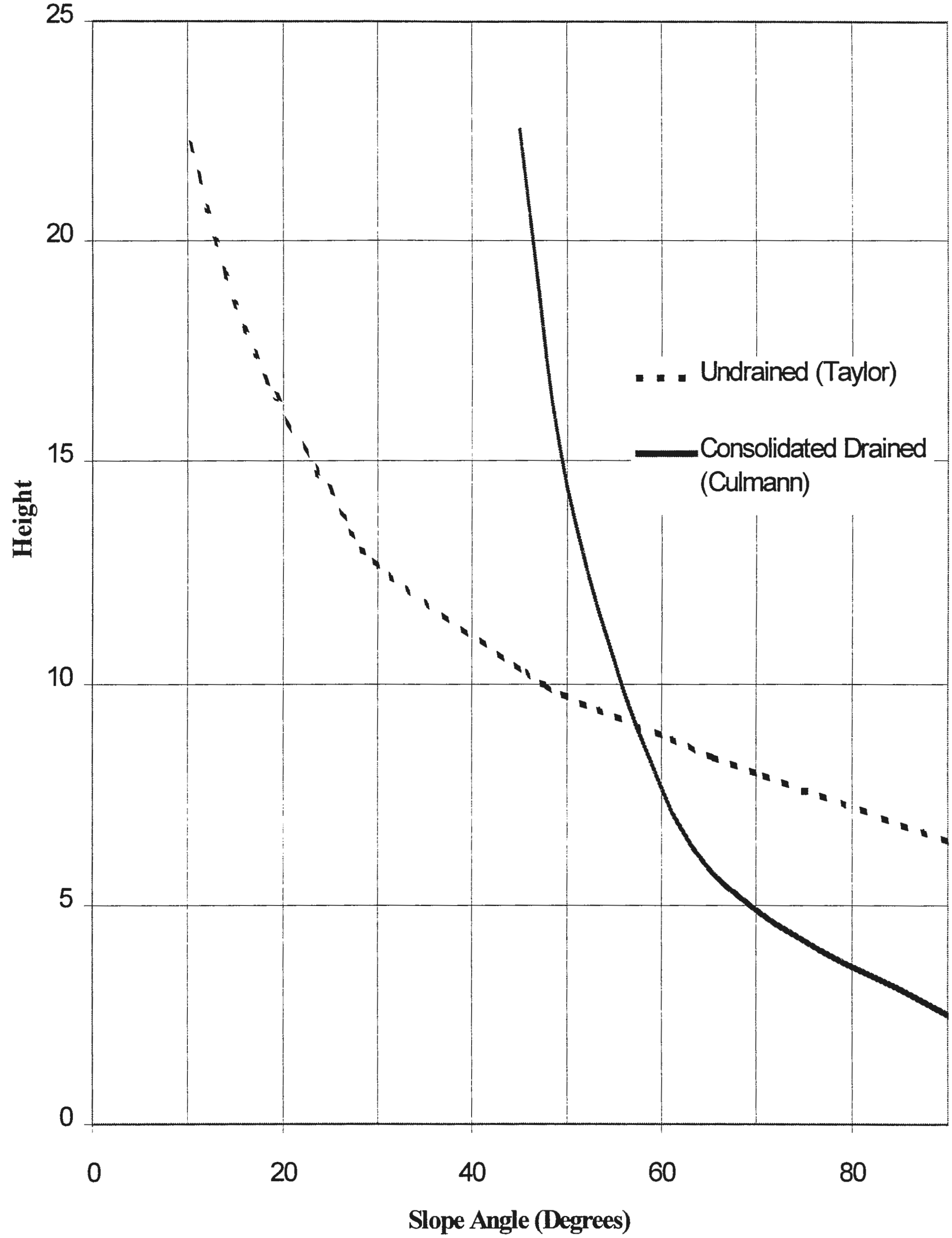


Figure 5.6 Plastic Loess

5.4 Discussion

The above results apply to cut slopes in natural materials. The undrained response curves for alluvium, loess derived alluvium, glacial till and plastic loess are very similar while friable loess gives lower stable slope angles for the same slope height. The consolidated drained response curves for glacial till and plastic loess are very similar while alluvium and friable loess give lower stable angles for the same slope height.

Considering both the undrained and drained responses, slope heights under the undrained curve between a slope angle of 10 degrees and the slope angle where the graphs intersect should be stable. After the intersection point, slope heights governed by the drained curve are more critical to stability.

CHAPTER 6. A CASE STUDY: MURRAY HILL, HARRISON COUNTY

6.1 Introduction

The objective of the work reported in this chapter is to investigate the probable cause(s) and to suggest a repair method of a natural slope (backslope) failure in loess. The site, called Murray Hill, is located approximately 2 miles (3.2 km) northeast of Little Sioux, on County Highway F20 as indicated by "X" on the map in Figure 6.1

6.2 Geologic Setting

Murray Hill is situated in the steep sloped loess hills area of northwest Harrison County, Iowa. The subsoil profile in the area typically consists of a thick layer of aeolian silt over glacial till and bedrock. The upper layer is Peorian aged loess, up to 50 feet or more in thickness, and is often underlain by Loveland aged loess. The soil is often referred to as a friable loess. The soil in the upland drainageways and footslopes often consists of alluvial-colluvial soils that have eroded and migrated from the higher elevated hills (PSI, 1998).

The soil series is Hamburg silt loam with 40 to 75 percent slopes (Jury and Fisher, 1976). Erosion and gullying are serious harzards. Slump blocks, about 1 foot (0.3m) high, often called "catsteps", are predominant features. The slopes are very steep, and the soil is very erodible in cuts and on embankments. The soil also has low shrink-swell potential. Hamburg silt loam contains very little organic-matter, and has moderate alkaline and calcareous contents. The permeability of the soil is moderately high. The available water capacity is high, but the runoff is so rapid that the soil seldom soaks up enough moisture to reach capacity (Jury and Fisher, 1976). This suggests that soil saturation is unlikely.

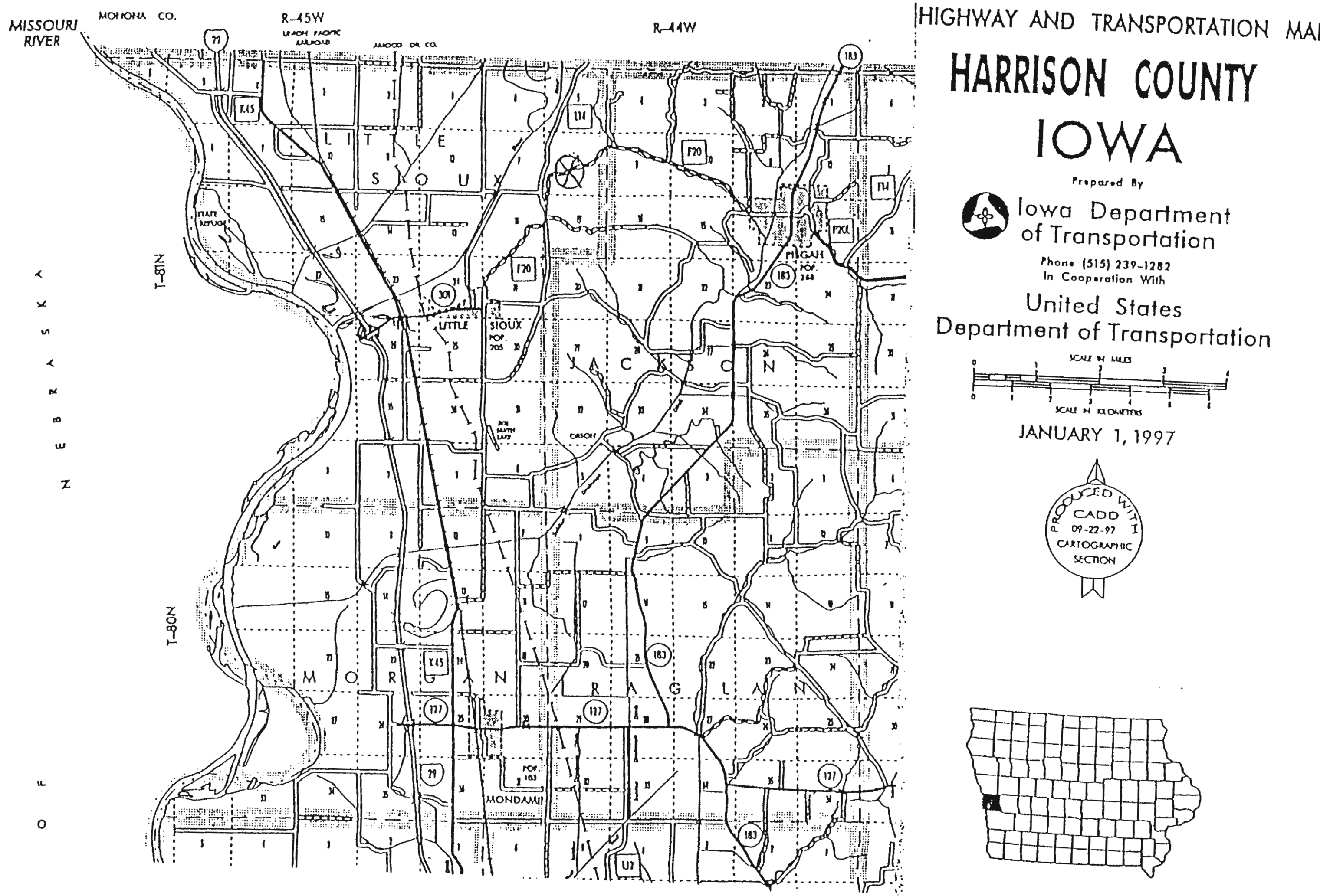


Figure 6.1 Location of Murray Hill

6.3 Description of the Slide

The slide is 170 feet (52 m) above the Missouri River floodplain, and is located near the upper part of a slope in the upland bluffs. The slopes adjacent to the roadway are vegetated with grasses and trees. During the ISU site investigation in June 1999, a 46-foot (14 m) long longitudinal crack was observed along the edge of the existing asphalt pavement; an 8-foot (2.5 m) wide zone had settled 3 inches (8 cm) due to slope movement associated with the crack (see figure 6.2). An old trail about 10 feet (3 m) wide is at the bottom of the slope failure. The trail is about 25 feet (7.5 m) below the roadway. Three slope profiles were measured and the locations of the profiles are shown in Figure 6.2. As shown in Figure 6.3, the original slope profile (ISU3) is 41 degrees in the upper portion and 51 degrees in the lower portion. The slope profile in the failed region (ISU2) is shown in Figure 6.4.

6.4 Previous Study at Murray Hill

The Harrison County Engineer authorized a consulting company to investigate the slope on September 10, 1998. The consulting company submitted a report to the County Engineer on October 29, 1998. The report included three slope profiles and stratigraphic and geotechnical testing information from three borings. Undisturbed samples were collected. The consultant performed two sets of triaxial tests to obtain the soil shear strength parameters

On comparing the slope profiles submitted by the consultant with the slope profiles obtained during the ISU site investigation, it was found that the profiles submitted by the consultant were inaccurate. The consultant reported that the lower parts of the slope profiles were vertical (90 degrees) while the upper portions were 34 to 50 degrees. During the site investigation for this study, the lower slope angles were measured in a range from 37 to 51 degrees and the upper slope portions ranged from 41 to 51 degrees.

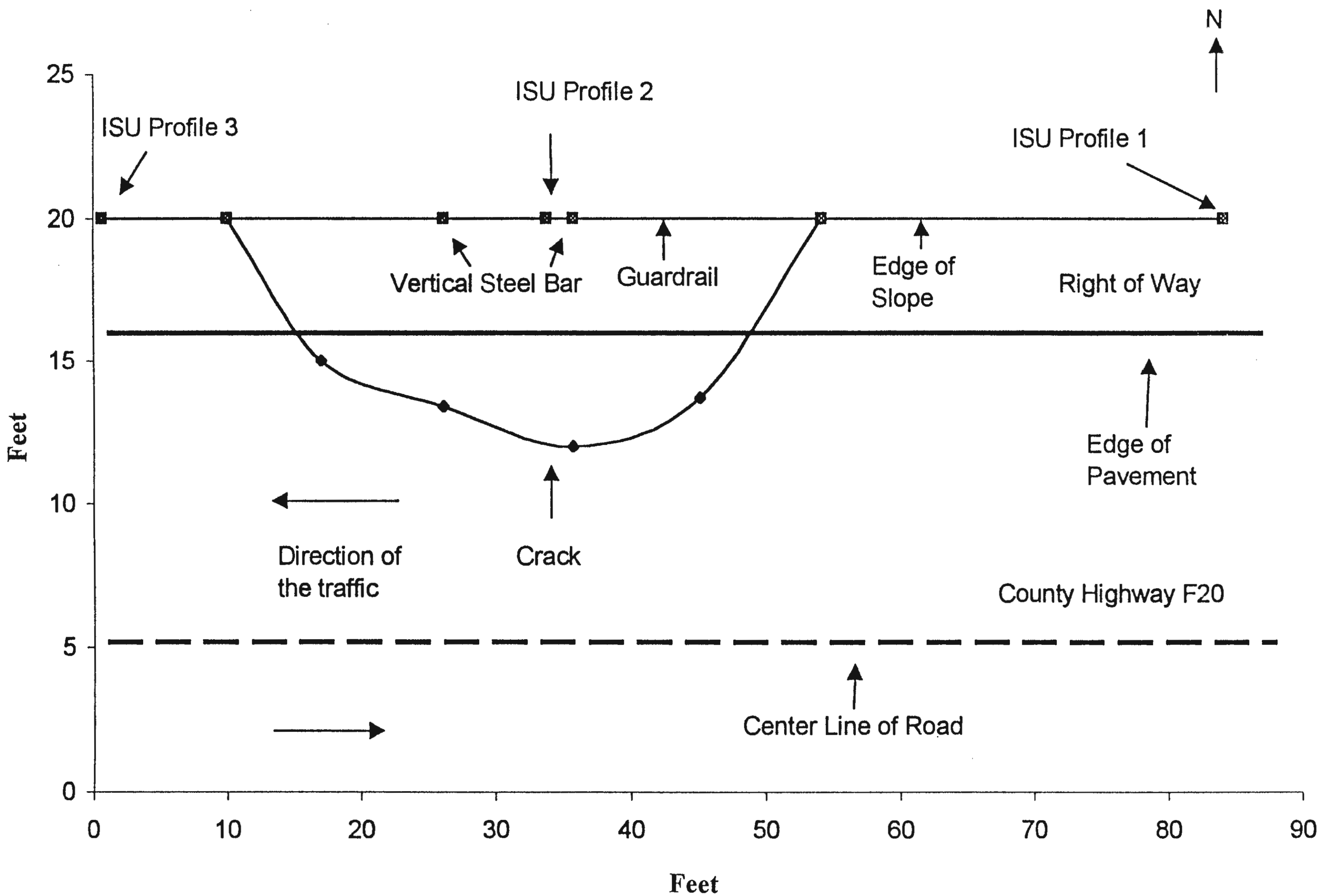


Figure 6.2 Plan of Slope Profile

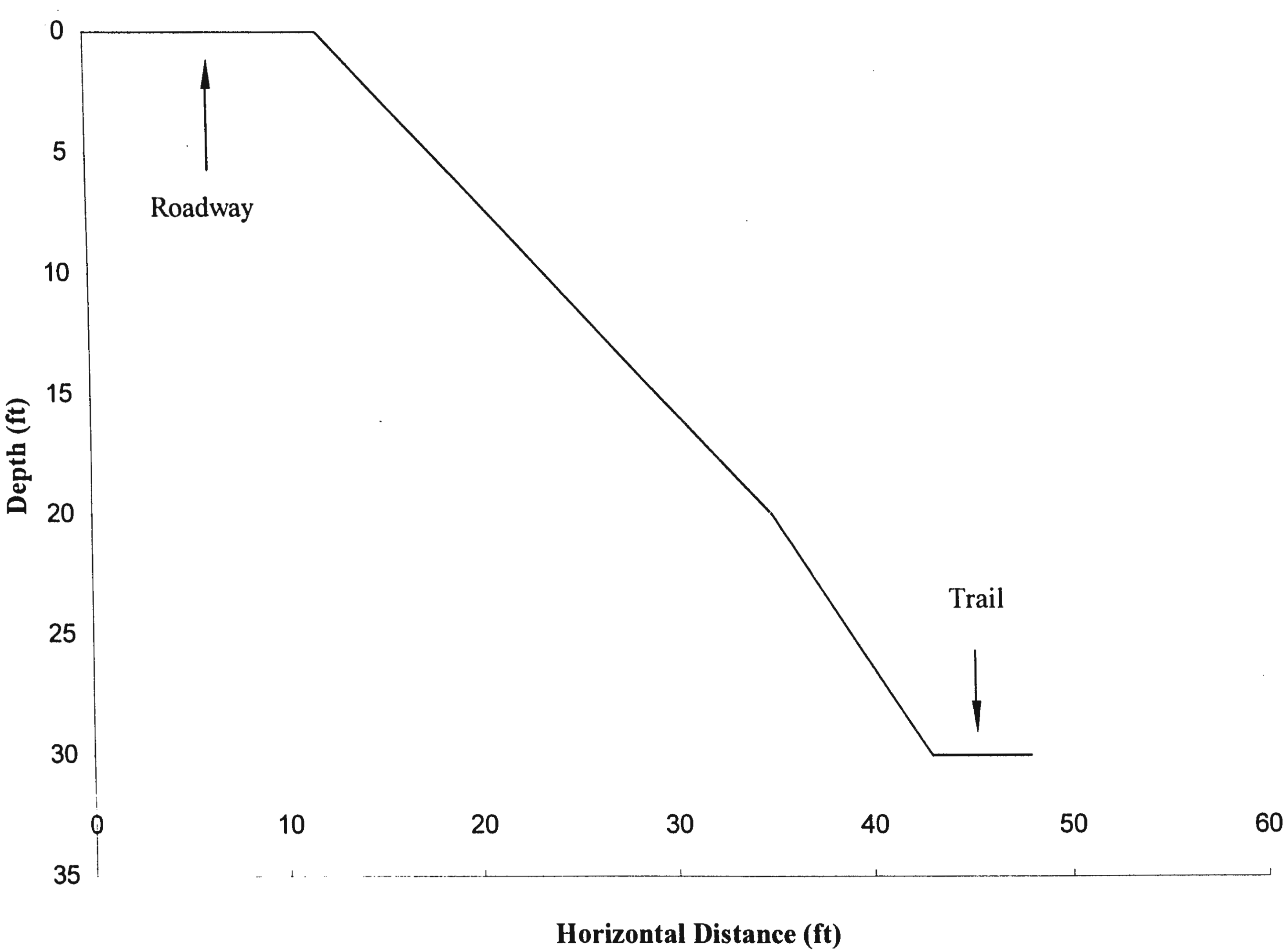


Figure 6.3 Murray Hill Original Slope Profile (ISU3)

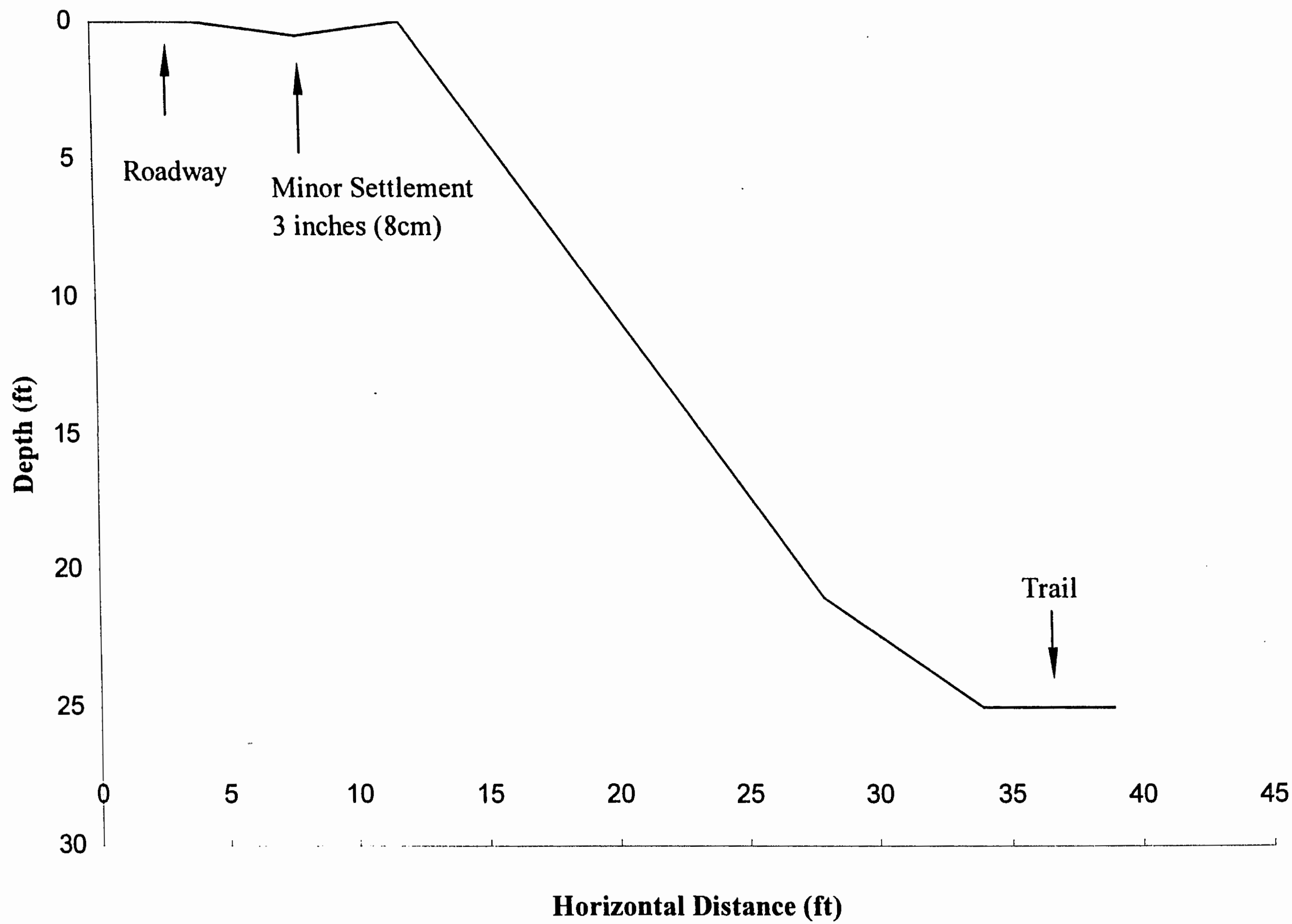


Figure 6.4 Murray Hill Slope Profile in Failed Region (ISU2)

In the consultant's boring logs, some saturation values were inaccurately calculated. The consultant reported some of the saturations in a range from 80 to 100%. Using the dry unit weight and moisture content values reported by the consultant, with a specific gravity of 2.70, the correct degree of saturation is from 42 to 55%.

The consultant claimed that Unconsolidated Undrained (UU) triaxial tests were performed; however the graphs in the report are more typical of Consolidated Drained (CD) triaxial tests. This response is likely due to the low degree of saturation. In addition, the height to diameter ratio of the samples tested was 1.2:1 and 1.5:1. The minimum height to diameter ratio recommended by ASTM is 2:1. The consultant reported the two sets of soil shear strength parameters and saturation shown in Table 6.1. A friction angle of 30 degrees for both sets of data, a zero cohesion intercept for one set of data, and a cohesion intercept of 27 kPa for the second set were reported. The zero cohesion with a 30 degree friction angle is unreasonable for slope angles between 34 and 51 degrees. Previous studies have indicated cohesion of about 12 kPa for friable loess at natural moisture content and about 5 kPa when back pressure saturated. (Olson, 1958, Akiyama, 1964, Benak, 1967)

Table 6.1 Soil Parameters and Saturation Reported by Consultant

Boring Log	Cohesion (kPa)	Friction Angle (degrees)	Saturation (%)	Minimum Safety Factor From XSTABL
B3	27	30	44	2.0
B1	0	30	48	0.4

No slope stability analyses were reported by the consultant. Using the soil strength parameters and unit weights provided by the consultant and the ISU3 slope profile, a stability analysis using the Simplified Bishop method in the XSTABL program was performed. Minimum safety factors of 2 and 0.4 were calculated for each set of data as shown in Table 6.1. The safety factor of 0.4 is for the zero cohesion test results. The inappropriate test procedures and lack of agreement of these strengths results with previous studies create doubt about the lower safety factor calculated here.

6.5 ISU Soil Sampling

For this study, seven Shelby tube samples were obtained from one boring. The samples were tested to determine the unit weight and shear strength parameters of the soil. A subsurface log of the boring is presented in Figure 6.5. The boring log indicates a layer of gray brown silt to a depth of 26 feet (8 m) underlain by a 9-foot (2.7 m) thick layer of brown gray silt. No water was observed in the borehole.

6.6 Geotechnical Properties

6.6.1 Engineering Index Properties

Atterberg limit tests and mechanical analyses were performed on two Shelby tube samples. The liquid limit for both samples is 32%. The plastic limits are 26 and 25%, and the plasticity indices are 6 and 7%. These data are shown in Table 6.2. The soil sample (2457B2) at a depth of 10 feet (3 m) had 71% of the soil particles passing through the 0.075mm (No. 200) sieve whereas the soil sample (2457C1) at a depth of 30 feet (9 m) had 53% of the soil particles passing through 0.075mm (No. 200) sieve. Both soils are classified as ML (low plasticity silt) by the Unified Classification System, and A-4 under the AASHTO classification System.

BORING LOG NO. 6 (Hole# P-2457)

Project: Murray Hill (Harrison County)	Client:	
Surface Elevation: Datum:	Date Drilled:8/25/99 Drilling Depth (ft): 36	Drilling Method: Page: 1 of 1

Elev. (ft)	Depth (ft)	Sample No.	Type	SPT bpf	Moisture (%)	Dry Density (pcf)	Unconfined Compressive Strength (psf)	Material Description	Graphic Log	USCS	Water Level	Depth (ft.in)	Elev. (ft)
								-Stiff GR BR Silty Clay & Gravel (Fill)				1'	
	–4	B-1	ST										
	–8												
		B-2	ST										
	–12												
		B-3	ST										
	–16												
		B-4	ST										
	–20												
	–24	B-5	ST										
								-Stiff to Firm GR BR Silt				26'	
	–28												
		C-1	ST										
	–32												
		C-2	ST										
								-Stiff to Firm BR GR Silt -Dry				35'2" 35'2"	
	–36												

Figure 6.5 Murray Hill Boring Log

Table 6.2 Engineering Index Properties for Murray Hill Soil Samples

Sample	Moisture Content (%)			Classification	Group Symbol	Group Name	AASHTO Classification
	Liquid Limit	Plastic Limit	Plasticity Index				
2457 B2	32.3	26.2	6.1	Low Plasticity	ML	Silt with Sand	A-4
2457 C1	31.6	24.5	7.1	Low Plasticity	ML	Sandy Silt	A-4

6.6.2 Effective Stress Shear Strength

Triaxial tests were performed on the Shelby tube samples to obtain the shear strength parameters of the soil. Consolidated drained (CD) tests were carried out under natural moisture content conditions. The deviator stress versus axial strain curves were plotted. These stress-strain curves and stress paths are shown in Appendix B. Using the maximum values from the stress-strain curves, the effective stress K_f line was plotted and the "a" and "α" values were obtained by linear regression as shown in Figure 6.6. These values were converted to "c" and "ϕ" values where the cohesion intercept "c" is 98.79 psf (4.73 kPa) and the internal friction angle "ϕ" is 30.1° for these soil samples. When compared with data reported in the literature, the cohesion intercept measured here is low.

6.7 Shear Strength Parameters from Literature Review

Data from a literature review for both natural moisture content and back-pressure saturated conditions were also used in the slope stability analysis. Table 6.3 shows the average shear strength parameters reported by Olson (1958), Akiyama (1964), and Benak (1967) for the Hamburg soil. The shear strength parameters obtained as part of this study are included in the same table.

By referring to Table 6.3, when comparing soil shear strength information from the literature review, it is apparent that the cohesion intercept "c" value will be lower if the tests are performed under saturated conditions. This observation is similar to that of Badger (1972) who observed that the cohesion intercept is inversely proportional to the degree of saturation. He based his conclusion on a series of unconfined compression tests on undisturbed loess.

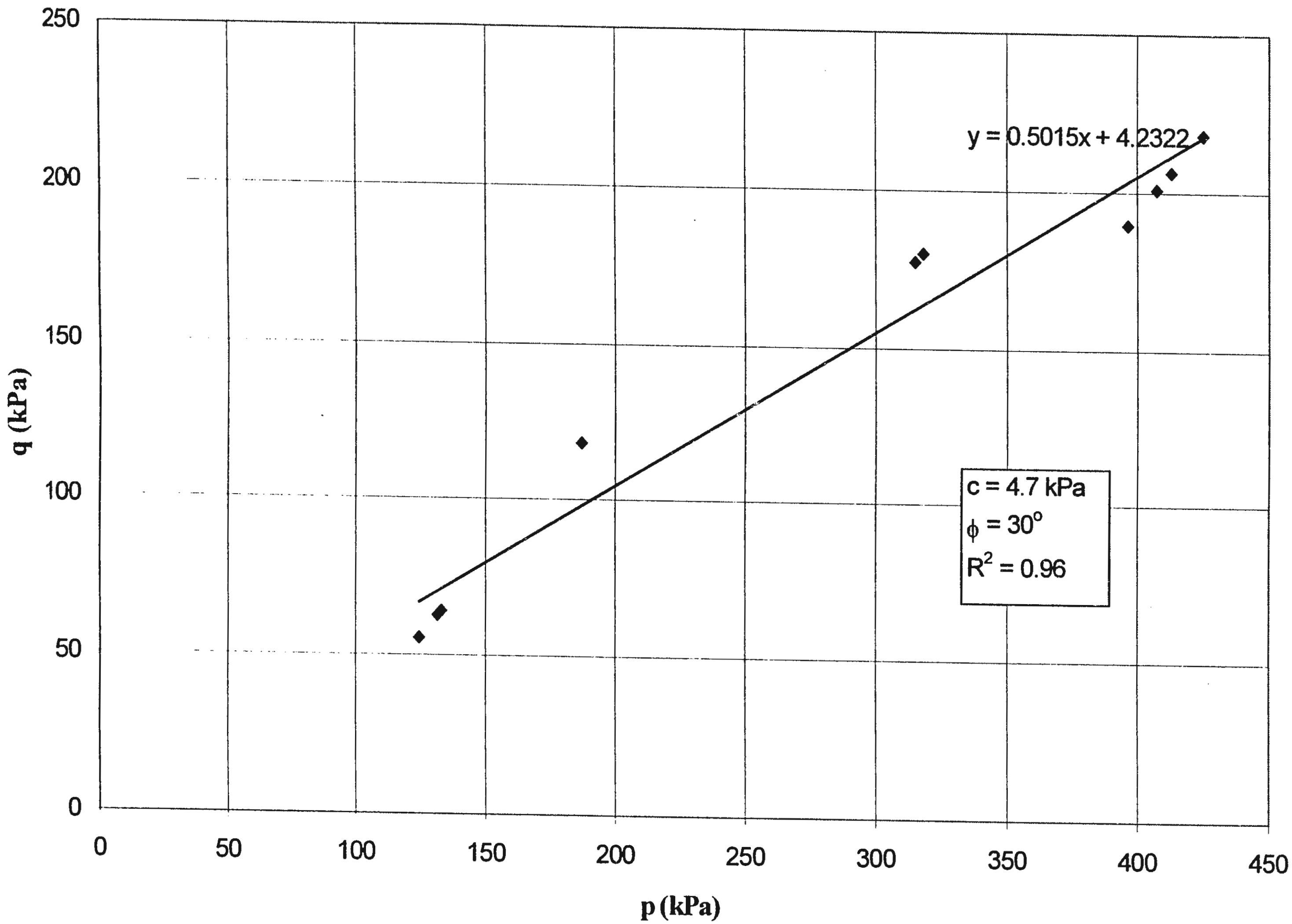


Figure 6.6 Natural Moisture Content p-q Diagram

Table 6.3 Shear Strength Parameter and Safety Factor under Different Condition for Murray Hill

Sources	Saturation (%)	Cohesion (kPa)	Friction Angle (degrees)	Unit Weight (kN/m^3)	Surcharge	Safety Factor
ISU	45	4.7	30	15.5	No	1.1
ISU	45	4.7	30	15.5	Yes	0.8
Literature Review[1]	33	12.4	29	14.9	No	1.5
Literature Review[1]	33	12.4	29	14.9	Yes	0.9
Literature Review[2]	100	5.1	26	15.1	No	1.0

1. Akiyama 1964, Benak 1967
2. Olson 1958, Akiyama 1964

6.8 Causes of Failure

The slope was analyzed by using the XSTABL computer software and Simplified Bishop method. A typical analysis is shown in Figure 6.7; a natural moisture content condition and the corresponding shear strength parameters were assumed for the analysis. Using the soil strength parameters from this study (ISU), the minimum safety factor is 1.1. Using the soil strength parameters from the literature review, the minimum safety factor is 1.5 when the soil is at natural moisture content; however, the safety factor decreases to 1.0 for a saturated condition. The results are shown in Table 6.3. The high topographic position of the site and soil characteristics make it unlikely that the loess was ever saturated.

During fieldwork, trucks were observed to pass close to the edge of the road. Therefore, a slope stability analysis XSTABL with a surcharge load from the trucks was performed. The vehicle surcharge loading represented a tandem truck; a stress of 17000 psf (814 kPa) was applied on each tire in the location shown in Figure 6.8. Using the soil strength parameters from this study (ISU), the safety factor decreases to 0.8 when the surcharge is included, as shown in Figure 6.8. The failure surface shown in Figure 6.8 extends further back into the roadway at the crest of the slope than the cracks observed on the pavement. Minimum factor of safety values under vehicle surcharge loading and different degree of saturation testing conditions were calculated by using XSTABL. The results are shown in Table 6.3. The safety factor of 1.1 without surcharge indicates a metastable condition while the addition of surcharge clearly suggests failure.

6.9 Suggested Repair Methods

As truck weight is a likely cause of failure, a stability analysis using more right-of-way was performed. As shown in Figure 6.9, the results from XSTABL analyses show that

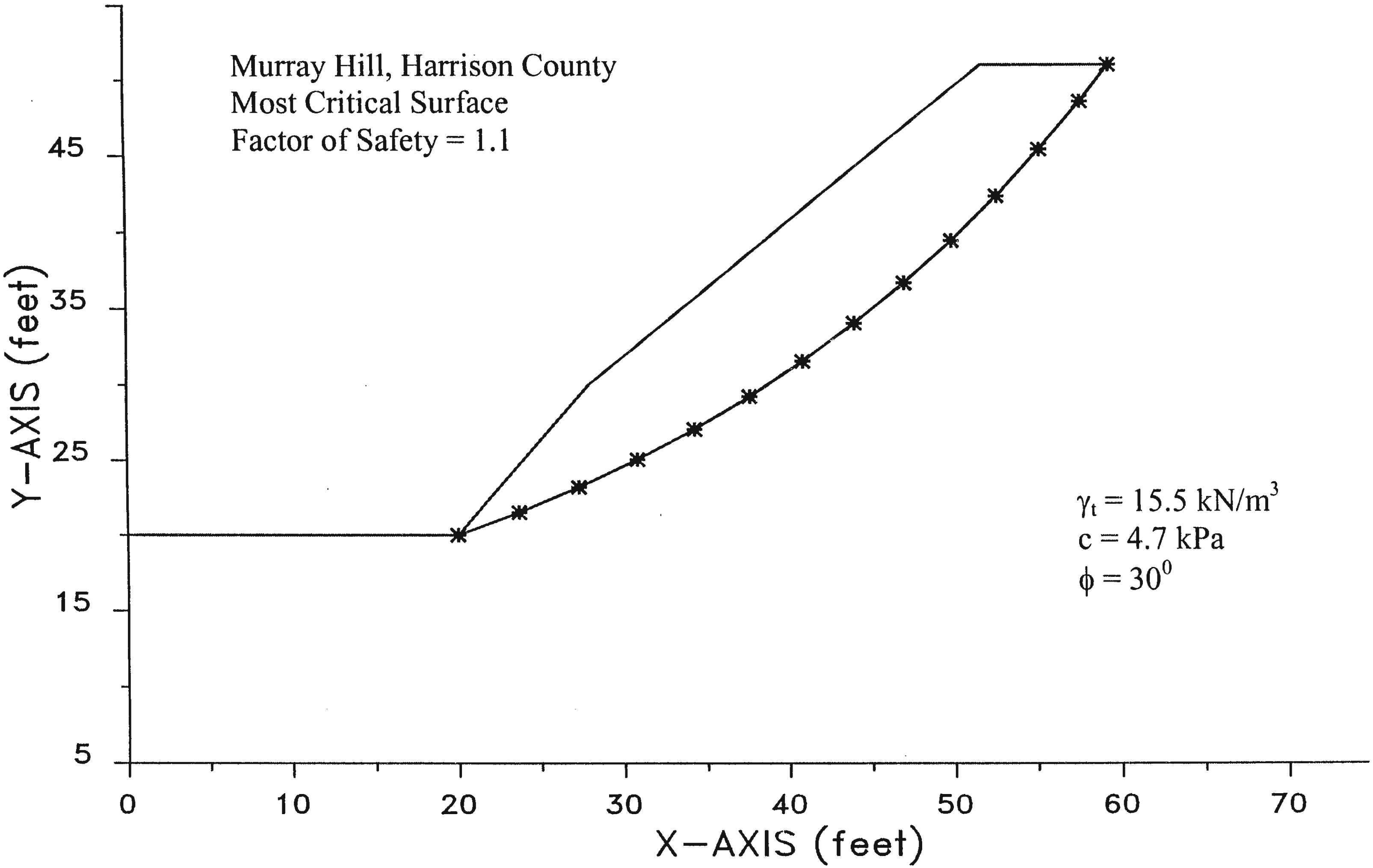


Figure 6.7 Slope Failure Profile Under Natural Moisture Content Condition

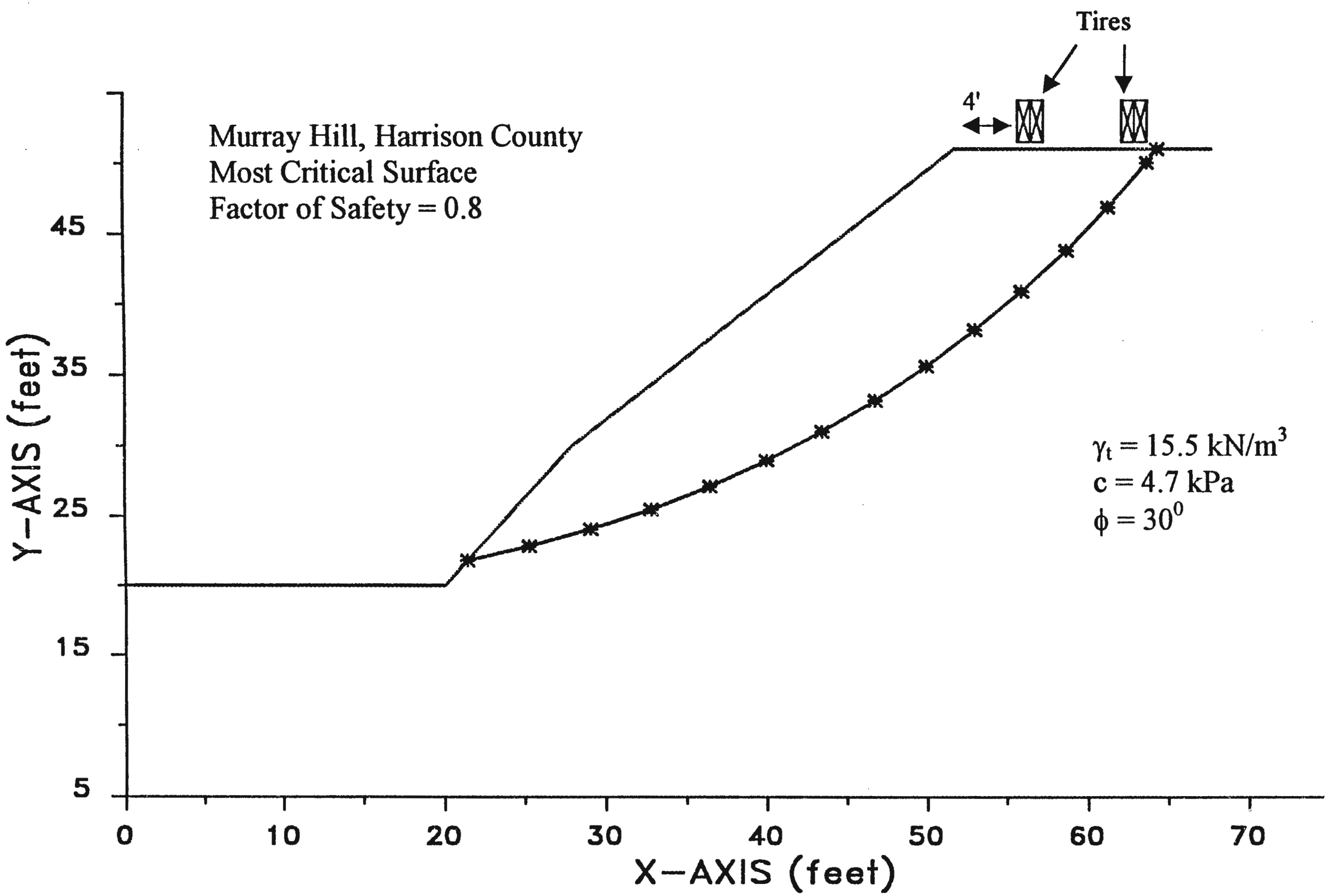


Figure 6.8 Slope Failure Profile After Applying Truck Load

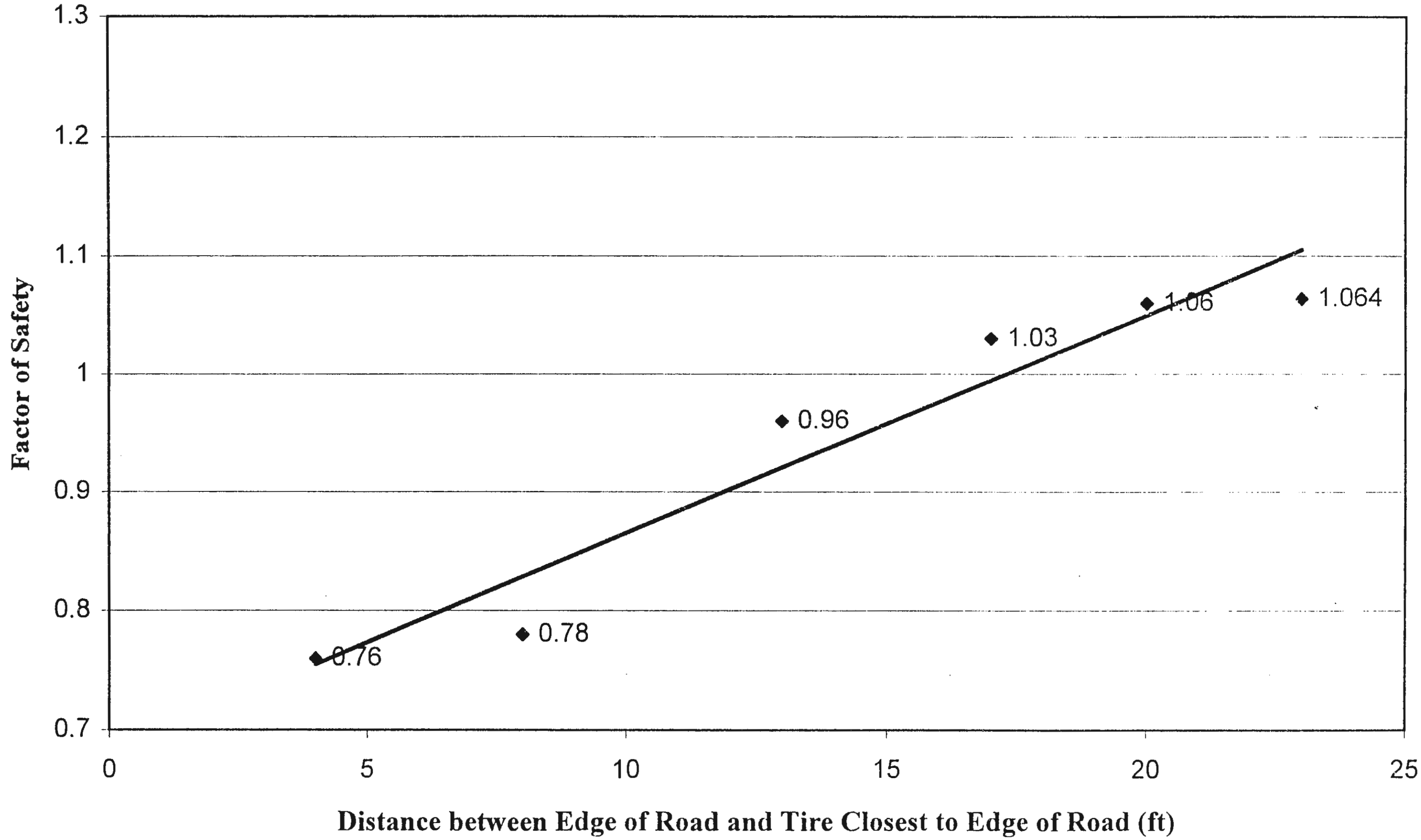


Figure 6.9 Relationship between Safety Factor and Distance of Tire from Edge of Road

the further the truck is away from the edge of the slope, the higher the minimum safety factor of the slope will be. Therefore, shifting the highway from the current location to at least 17 feet (5.2 m) away from the edge of the slope will at least provide a metastable condition. Shifting the highway as far from the edge of the slope as possible would be the most effective and economical way to repair this failure. In addition, sealing the crack that was found along the road will minimize water infiltration, and hence minimize the loss of soil strength and any potential buildup of pore pressures along the failure surface. Relocation of the roadway combined with a buttress founded on the trail at the bottom of the slope, if deemed necessary, should give a reasonable safety factor. Further analyses of the slope downslope of the proposed buttress should be carried out to insure that if a buttress is installed, loading will not create stability problems downslope of this slide.

6.10 Summary

Stability analyses indicate that this slope should be metastable, with a safety factor of 1.1, under natural moisture conditions. Imposing a surcharge truck load at the edge of the road reduces the safety factor to 0.8. Moving the surcharge load further from the edge of the road increases the safety factor.

Therefore it is interpreted that surcharge loading is a likely cause of the failure. Moving the current roadway to at least 17 feet (5.2 m) away from the edge of the slope will increase stability. The interpretations presume the accuracy of the strength data and the validity of assumptions used in the stability analysis.

CHAPTER 7. CONCLUSIONS

A landslide survey of Iowa County engineers was conducted and the results were used to create an Iowa slope stability risk map. Of the 60 counties that responded to the survey on landslides, 80% reported landslide activity and among the counties with landslide activity, 31% of the them had more than 11 landslides since 1993. On a statewide basis, most of the slides occur in foreslopes composed of undifferentiated fill. Both curvilinear and planar failure surfaces were observed throughout the state and the landslides occurred during spring and summer, with 50% of the failures caused by groundwater. Nearly all of the slope failures occurred in slopes steeper than 3:1 with the majority failures in slopes of between 1:1 and 2:1. Most of the slides occurred in slopes between 11 and 20 ft high before failure. The most common and successful repair procedures have employed drainage and slope flattening.

A database of soil shear strength parameters and unit weights was developed based on the data from the literature review, Iowa DOT and engineering consultants' files. Mean values of shear strength parameters and unit weights were computed and classified according to geologic parent material. A statistical t-test analysis was carried out to determine if the differences in mean value of shear strength parameters and unit weights between different geologic materials are statistically significant. Based on the consolidated undrained (CU) data from Iowa DOT files, here interpreted as an unconsolidated undrained (UU) response, the total unit weight between alluvium and friable loess, dry unit weight between loess derived alluvium and glacial till, and between glacial till and friable loess shows a significant difference. Based on the consolidated undrained (CU) data with pore pressure measurement from the consultants and consolidated drained (CD) data from the literature review, there is a significant statistical difference for cohesion intercept between alluvium and glacial till, between alluvium and plastic loess, and between glacial till and plastic loess. A significant difference also exists for friction angle between glacial till and plastic loess, between friable loess and plastic loess, between friable loess and alluvium, and between friable loess and glacial till. For dry unit weight, there is a significant difference between friable loess and alluvium. For total unit weight, a significant difference was found between glacial till and plastic loess, and between friable loess and alluvium. A significant difference was found between alluvium and plastic loess, and also between friable loess and alluvium. The cohesion intercepts and friction angles of these data compared well with results from similar tests on similar materials from the current research. Effective stress cohesion intercept and undrained shear strength data, do, however, show a high degree of variation.

Curves showing stable slope height versus slope angle were plotted based on Culmann (drained) and Taylor (undrained) analyses. The undrained response curves for alluvium, loess derived alluvium, glacial till and plastic loess are very similar while friable loess gives lower stable slope angles for the same height. The consolidated drained response curves for glacial till and plastic loess are very similar while alluvium and friable loess give lower stable angles for the same slope height. Combinations of slope height and slope angle that fall below both of the curves represents stable conditions while those above one of the curves represents instability.

In the case study, stability analyses indicate that the Murray Hill slope in western Iowa loess in Harrison County should be metastable, with a minimum safety factor of 1.1. Imposing surcharge truck load at the edge of the road reduces the minimum safety factor to 0.8. Moving the surcharge load further from the edge of the road increases the safety factor.

Shifting the current roadway to at least 17 feet (5.2 m) away from the edge of the slope will restore the metastable condition.

CHAPTER 8. RECOMMENDATIONS FOR FURTHER STUDY

Further study should be done on the soil shear strength database for preliminary slope stability guidelines. The undrained shear strength data and effective stress data were obtained from different sources. This means that the consistency of the results may be affected by different testing methodologies and equipment used by different sources. If time and financial consideration are not an issue, more undisturbed samples from different geologic materials should be obtained and tested under the same testing methodologies. Another way to improve the database for preliminary slope stability guidelines is to collect and compile more data for different geologic materials. For example, only 4 sets of values were used to represent the undrained shear strength for glacial till. This means that the mean and standard deviation of these data are likely not precise.

Only four case histories, one reported in this thesis and three reported in the thesis of another research assistant, Bhooshan Karnik, were studied and analyzed for this research. More landslide case histories in different geological materials and at different locations (foreslope, backslope, natural slope, along stream bank) should be studied and analyzed, and each case study should employ more extensive soil test.

APPENDIX A

QUESTIONNAIRE SAMPLE

Questionnaire

1) What is your County?

____

2) What is your name, phone number and email?

____

3) Has your county ever experienced a landslide/slope stability problem?

   (a) Yes (Please continue)

   (b) No (Thank you for your time)

4) How many landslides have occurred since January 1993? (Check the most appropriate number)

   (a) 1 to 5 ______

   (b) 6 to 10 ______

   (c) 11 to 15 ______

   (d) More than 15 ______

5) Where did the landslides in your county occur since January 1993? (Rank 1 to 5 with 1 being the most prevalent)

   Rank

   (a) Foreslopes (Embankments fills) ______

   (b) Backslopes (Cuttings) ______

   (c) Along stream or river banks ______

   (d) Natural slopes ______

   (e) Other ______________________________________

6) What kind of soil(s) was/were involved? (Check all that apply)

   (a) Glacial till ______

   (b) Loess ______

   (c) Alluvium ______

   (d) Shale / bedrock ______

   (e) Undifferentiated Fill ______

   (f) Other ______________________________________

7) What do you think is/are the cause(s) of slope failure since January 1993? (Check all that apply)

(a) Maintenance/construction activities (Excavation at toe of slope) ______

(b) Loading at the crest of slope ______

(c) Design issue (too steep) ______

(d) High ground water table ______

(e) After heavy rainfall ______

(f) Other____

For questions #8-11, please base your answer on your most frequently occuring slope failures.

8) What was/were the shape(s) of the slope failures? (Check all that apply)

(a) Planar (For example: ) ______

(b) Curvilinear (For example: ) ______

(c) Unknown ______

(d) Other____

9) What was/were the angle(s) of the slope(s) before failure? (Check all that apply)

(a) Steeper than 1:1 ______

(b) 1:1 to 2:1 ______

(c) 2:1 to 3:1 ______

(d) 3:1 to 4:1 ______

(e) Flatter than 4:1 ______

10) What was/were the height of the slope(s) before failure? (Check all that apply)

(a) 1 to 10 ft ______

(b) 11 to 20 ft ______

(c) 21 to 30 ft ______

(d) Greater than 30 ft ______

11) In what season of the year did most of the failures occur?

(a) Spring

(b) Summer

(c) Fall

(d) Winter

12) Do you repair slope failures?

(a) Yes

(b) No (Skip next question)

13) What methods have been applied to prevent and/or repair landslides since January 1993? (Check all that apply)

(a) Decrease slope angle	_____	Was it effective? (Yes / No)
(b) Load the toe	_____	Was it effective? (Yes / No)
(c) Improve water control	_____	Was it effective? (Yes / No)
(d) Slope flattening by benching	_____	Was it effective? (Yes / No)
(e) Structural support (Retaining wall)	_____	Was it effective? (Yes / No)
(f) Geo-synthetic stabilization	_____	Was it effective? (Yes / No)
(g) Chemical stabilization	_____	Was it effective? (Yes / No)

(h) Other ____

(i) Comments?____

14) Would you be willing to show us example(s) of landslide problem(s) in your county?

(a) Yes

(b) No

15) Additional comments or suggestions:

APPENDIX B

RAW DATA AND ANALYSIS

MURRAY HILL, HARRISON COUNTY

Shelby Data From Murray Hill (Harrison County) *Assume SG=2.7

P2457 B1

Number	Depth (ft. in.)	Wet Unit Wt. (lb/ft^3)	Wet Unit Wt. (KN/m^3)	Moisture Content (%)	Dry Unit Wt. (lb/ft^3)	Dry Unit Wt. (KN/m^3)	Degree of Sat. (%)
1	4'0" - 4'7"	101.59	15.97	13.69	89.35	14.05	41.74
2	4'7" - 5'2"	109.74	17.25	15.39	95.10	14.95	53.87

P2457 B2

Number	Depth (ft. in.)	Wet Unit Wt. (lb/ft^3)	Wet Unit Wt. (KN/m^3)	Moisture Content (%)	Dry Unit Wt. (lb/ft^3)	Dry Unit Wt. (KN/m^3)	Degree of Sat. (%)
1	9'0" - 9'7"	96.57	15.18	19.94	80.51	12.66	49.27
2	9'7" - 10'2"	98.39	15.47	19.68	82.21	12.92	50.64

P2457 B3

Number	Depth (ft. in.)	Wet Unit Wt. (lb/ft^3)	Wet Unit Wt. (KN/m^3)	Moisture Content (%)	Dry Unit Wt. (lb/ft^3)	Dry Unit Wt. (KN/m^3)	Degree of Sat. (%)
1	14'0" - 14'7"	96.16	15.12	14.63	83.88	13.19	39.18
2	14'7" - 15'2"	99.53	15.65	14.89	86.63	13.62	42.54

P2457 B4

Number	Depth (ft. in.)	Wet Unit Wt. (lb/ft^3)	Wet Unit Wt. (KN/m^3)	Moisture Content (%)	Dry Unit Wt. (lb/ft^3)	Dry Unit Wt. (KN/m^3)	Degree of Sat. (%)
1	19'0" - 19'7"	92.49	14.54	15.30	80.22	12.61	37.54
2	19'7" - 20'2"	96.53	15.18	16.08	83.16	13.07	42.31

P2457 B5

Number	Depth (ft. in.)	Wet Unit Wt. (lb/ft^3)	Wet Unit Wt. (KN/m^3)	Moisture Content (%)	Dry Unit Wt. (lb/ft^3)	Dry Unit Wt. (KN/m^3)	Degree of Sat. (%)
1	24'0" - 24'7"	96.51	15.17	15.95	83.23	13.08	42.05
2	24'7" -25'2"	97.57	15.34	16.12	84.02	13.21	43.31

P2457 C1

Number	Depth (ft. in.)	Wet Unit Wt. (lb/ft^3)	Wet Unit Wt. (KN/m^3)	Moisture Content (%)	Dry Unit Wt. (lb/ft^3)	Dry Unit Wt. (KN/m^3)	Degree of Sat. (%)
1	29'0" - 29'7"	98.08	15.42	14.90	85.37	13.42	41.31
2	29'7" - 30'2"	99.25	15.60	18.94	83.45	13.12	50.18

Notes: Due to the difficulty to generate enough force to extrude the soil by using manual extruder, the shelby tubes were cut into 7 inches long and extruded by hydraulic jack.

Atterberg Limit for Murray Hill (Harrison County)

2457B2

Liquid Limit, LL

Trial #	1	2	3
# Blow	21	14	9
Wt. Of Dish + Air-dry Soil (g)	33.68	29.11	25.56
Wt. Of Dish + Oven-dry Soil (g)	29.36	25.91	23.31
Wt. Of Moisture (g)	4.32	3.2	2.25
Wt. Of Dish (g)	16.42	16.74	17.13
Wt. Of Oven-dry Soil (g)	12.94	9.17	6.18
Moisture Content (%)	33.38	34.90	36.41

Plastic Limit, PL

Trial #	1	2	3
Wt. Of Dish + Air-dry Soil (g)	26.31	25.32	24.58
Wt. Of Dish + Oven-dry Soil (g)	24.83	23.17	23.15
Wt. Of Moisture (g)	1.48	2.15	1.43
Wt. Of Dish (g)	19.21	14.81	17.79
Wt. Of Oven-dry Soil (g)	5.62	8.36	5.36
Moisture Content (%)	26.33	25.72	26.68

2457C1

Liquid Limit, LL

Trial #	1	2	3
# Blow	28	26	16
Wt. Of Dish + Air-dry Soil (g)	26.83	26.59	25.91
Wt. Of Dish + Oven-dry Soil (g)	24.59	24.1	23.6
Wt. Of Moisture (g)	2.24	2.49	2.31
Wt. Of Dish (g)	17.36	16.16	16.7
Wt. Of Oven-dry Soil (g)	7.23	7.94	6.9
Moisture Content (%)	30.98	31.36	33.48

Plastic Limit, PL

Trial #	1	2	3
Wt. Of Dish + Air-dry Soil (g)	21.83	23.86	15.7
Wt. Of Dish + Oven-dry Soil (g)	20.59	22.31	14.76
Wt. Of Moisture (g)	1.24	1.55	0.94
Wt. Of Dish (g)	15.6	15.47	11.15
Wt. Of Oven-dry Soil (g)	4.99	6.84	3.61
Moisture Content (%)	24.85	22.66	26.04

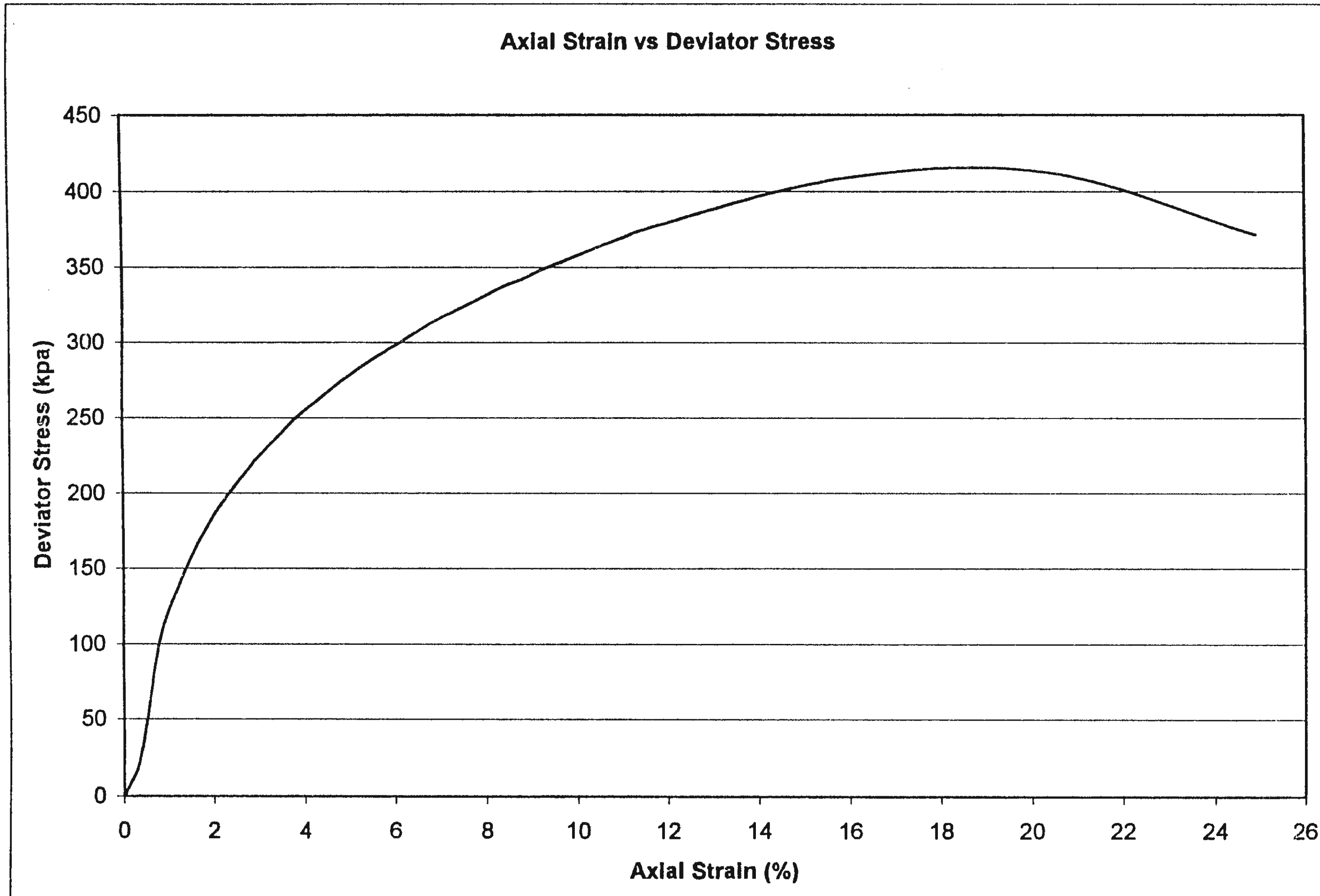
CD30 Test Results

Harrison County

Sample No. 2457/B1/1
Test Date : 10/13/99

	Consolidated-drained test on loess													
note "MEMBRANE LEAK"														
	Test No.	4												
	Name	cd30	2457/B1/1											
	Initial	Initial	Initial	Confining	Confining	Bef. Cons	Af. Cons	Bef. Cons	Af. Cons	Void	Dry Unit	Dry Unit	Dry Unit	
	Height	Diamete	Volume	Pressure	Pressure	VC	VC	H	H	Ratio	Weight	Weight	Weight	
	142	72.7	589.45	30	206.84	33.32	73.99	0.02	0.06	ei	(g/cm^3)	(pcf)	(pcf)	
	(mm)	(mm)	(cm^3)	(psi)	(kPa)	(cm^3)	(cm^3)	(in)	(in)	0.984	1.36	84.91	91.20	
				Bef Cons					Aft Cons					
	Specimen	Moistur	Specific	Specimen	Specimen	Specimen	Specimen	Volume	Height	Diameter	Volume	Volume	Void	Dry Unit
	Weight	Content	Gravity	Height	Diameter	Area	Volume	after Cons	after Cons	after Cons	Solid	Voids	Ratio	Weight
	(g)	(%)	(g/cm^3)	(cm)	(cm)	(cm^2)	(cm^3)	(cm^3)	(cm)	(cm)	(cm^3)	(cm^3)	e_o	(g/cm^3)
	979	22.06	2.7	14.2	7.27	41.51	589.45	548.78	14.10	7.04	297.06	251.72	0.847	1.46
Reading	Axial	Axial	Volume	Corrected	Volume	Corrected	Axial	Axial	Axial	σ_1	p	q		
	Deflection	Strain	Change	VC	Change	Area	Load	Load	Stress					
	(in)	(%)	(cm^3)	(cm^3)	(%)	(cm^2)		(lb)	(kPa)	(kPa)	(kPa)	(kPa)		
1057	0.06	0	74.0	0	0	38.9	0.3	3	0	206.84	206.84	0		
1056	0.08	0.360	73.9	-0.31	-0.06	39.1	2.5	25	25.04	231.88	219.36	12.52		
1066	0.105	0.811	74.6	0.09	0.02	39.2	9.4	94	103.17	310.01	258.43	51.58		
1081	0.129	1.243	75.7	0.85	0.16	39.4	12.7	127	140.16	347.00	276.92	70.08		
1095	0.154	1.694	76.7	1.53	0.28	39.5	15.3	153	168.98	375.83	291.33	84.49		
1106	0.178	2.126	77.4	2.01	0.37	39.6	17.3	173	190.84	397.68	302.26	95.42		
1116	0.203	2.576	78.1	2.41	0.44	39.8	19	190	209.11	415.95	311.40	104.56		
1126	0.228	3.027	78.8	2.81	0.51	39.9	20.5	205	225.01	431.85	319.35	112.50		
1133	0.252	3.459	79.3	3.02	0.55	40.1	21.8	218	238.51	445.35	326.10	119.25		
1140	0.277	3.910	79.8	3.21	0.58	40.3	23.1	231	251.84	458.68	332.76	125.92		
1146	0.302	4.360	80.2	3.33	0.61	40.5	24.2	242	262.81	469.65	338.25	131.40		
1151	0.327	4.810	80.6	3.38	0.62	40.6	25.3	253	273.63	480.48	343.66	136.82		
1156	0.352	5.261	80.9	3.43	0.62	40.8	26.3	263	283.26	490.10	348.47	141.63		
1159	0.376	5.693	81.1	3.35	0.61	41.0	27.2	272	291.68	498.53	352.68	145.84		
1163	0.401	6.144	81.4	3.33	0.61	41.2	28.1	281	299.99	506.83	356.84	150.00		
1165	0.425	6.576	81.6	3.18	0.58	41.4	29	290	308.19	515.04	360.94	154.10		
1167	0.45	7.026	81.7	3.02	0.55	41.6	29.9	299	316.23	523.07	364.96	158.12		
1168	0.475	7.477	81.8	2.79	0.51	41.9	30.7	307	323.07	529.91	368.38	161.53		
1170	0.5	7.927	81.9	2.63	0.48	42.1	31.5	315	329.86	536.70	371.77	164.93		
1170	0.524	8.360	81.9	2.34	0.43	42.3	32.3	323	336.55	543.39	375.12	168.28		
1171	0.549	8.810	82.0	2.11	0.38	42.5	33	330	342.08	548.92	377.88	171.04		
1171	0.574	9.260	82.0	1.81	0.33	42.8	33.8	338	348.53	555.37	381.11	174.26		
1170	0.599	9.711	81.9	1.44	0.26	43.0	34.5	345	353.80	560.65	383.74	176.90		
1170	0.623	10.143	81.9	1.15	0.21	43.2	35.2	352	359.13	565.97	386.41	179.56		
1170	0.648	10.594	81.9	0.85	0.16	43.5	35.9	359	364.29	571.14	388.99	182.15		
1170	0.673	11.044	81.9	0.55	0.10	43.7	36.6	366	369.38	576.23	391.53	184.69		
1169	0.697	11.476	81.8	0.20	0.04	44.0	37.3	373	374.43	581.28	394.06	187.22		
1147	0.946	15.962	80.3	-4.33	-0.79	46.7	43.2	432	408.77	615.61	411.23	204.38		
1103	**1.195**	**20.448**	**77.2**	**-10.40**	**-1.90**	**49.9**	**46.5**	**465**	412.19	**619.03**	**412.94**	**206.09**		
1056	1.444	24.934	73.9	-16.68	-3.04	48.6	40.9	409	371.60	578.44	392.64	185.80		

CD30 Test Results Harrison County Sample No. 2457/B1/1
Test Date : 10/13/99



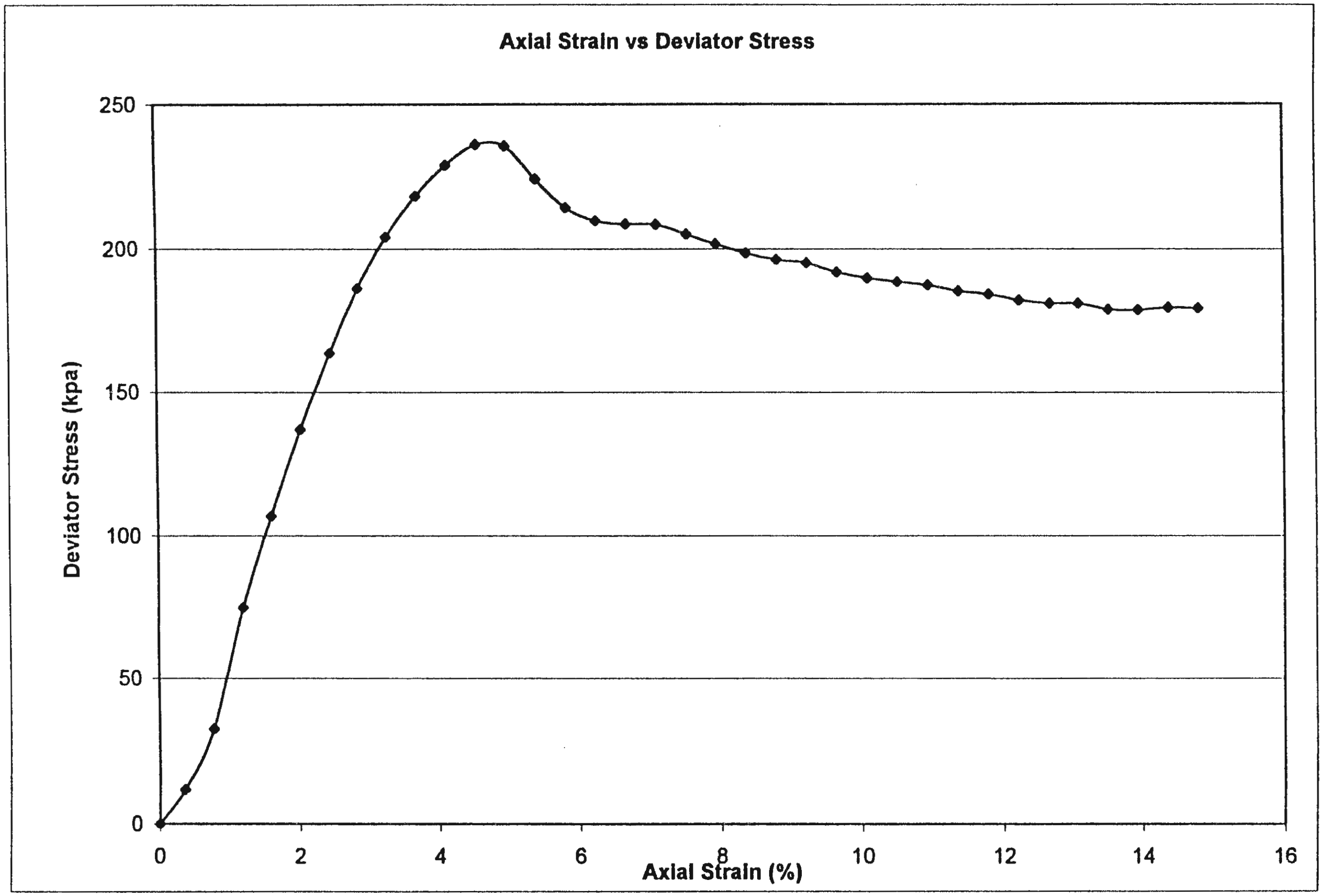
CD10 Test Results | Harrison County | Sample No. 2457/B1/2 Test Date : 10/12/99

	Consolidated-drained test on loess													
	Test No.	5												
	Name	cd10	2457/B1/2											
	Initial	Initial	Initial	Confining	Confining	Bef. Cons	Af. Cons	Bef. Cons	Af. Cons	Void	Dry Unit	Dry Unit	Dry Unit	
	Height	Diamete	Volume	Pressure	Pressure	VC	VC	H	H	Ratio	Weight	Weight	Weight	
	149	71.1	591.58	10	68.95	34.44	61.74	0.013	0.044	ei	(g/cm^3)	(pcf)	(pcf)	
	(mm)	(mm)	(cm^3)	(psi)	(kPa)	(cm^3)	(cm^3)	(in)	(in)	0.892	1.43	89.04	93.35	
				Bef Cons				Aft Cons						
	Specimen	Moistur	Specific	Specimen	Specimen	Specimen	Specimen	Volume	Height	Diameter	Volume	Volume	Void	Dry Unit
	Weight	Content	Gravity	Height	Diameter	Area	Volume	after Cons	after Cons	after Cons	Solid	Voids	Ratio	Weight
	(g)	(%)	(g/cm^3)	(cm)	(cm)	(cm^2)	(cm^3)	(cm^3)	(cm)	(cm)	(cm^3)	(cm^3)	e_o	(g/cm^3)
	1060	25.57	2.7	14.9	7.11	39.70	591.58	564.28	14.82	6.96	312.65	251.63	0.805	1.50
Reading	Axial	Axial	Volume	Corrected	Volume	Corrected	Axial	Axial	Axial	σ_1	p	q		
	Deflection	Strain	Change	VC	Change	Area	Load	Load	Stress					
	(in)	(%)	(cm^3)	(cm^3)	(%)	(cm^2)		(lb)	(kPa)	(kPa)	(kPa)	(kPa)		
882	0.044	0	61.7	0	0	38.1	0.4	4	0	68.95	68.95	0		
882	0.065	0.3599	61.7	-0.252	-0.04	38.2	1.4	14	11.64	80.58	74.77	5.82		
881	0.089	0.771	61.7	-0.61	-0.11	38.4	3.2	32	32.43	101.37	85.16	16.21		
887	0.114	1.200	62.1	-0.49	-0.09	38.6	6.9	69	74.97	143.91	106.43	37.48		
889	0.138	1.611	62.2	-0.64	-0.11	38.7	9.7	97	106.79	175.73	122.34	53.39		
888	0.163	2.039	62.2	-1.01	-0.18	38.9	12.4	124	137.10	206.05	137.50	68.55		
881	0.188	2.468	61.7	-1.80	-0.32	39.2	14.8	148	163.57	232.52	150.73	81.78		
870	0.212	2.879	60.9	-2.86	-0.51	39.4	16.9	169	186.29	255.23	162.09	93.14		
857	0.236	3.290	60.0	-4.05	-0.72	39.7	18.6	186	204.18	273.12	171.04	102.09		
841	0.261	3.719	58.9	-5.47	-0.97	39.9	20	200	218.36	287.31	178.13	109.18		
825	0.286	4.147	57.8	-6.89	-1.22	40.2	21.1	211	229.02	297.97	183.46	114.51		
808	**0.311**	**4.576**	**56.6**	**-8.38**	**-1.49**	**40.5**	**21.9**	**219**	236.19	**305.14**	**187.04**	**118.10**		
793	0.335	4.987	55.5	-9.72	-1.72	40.8	22	220	235.72	304.67	186.81	117.86		
781	0.36	5.415	54.7	-10.86	-1.92	41.0	21.1	211	224.43	293.38	181.16	112.22		
773	0.385	5.844	54.1	-11.72	-2.08	41.3	20.3	203	214.46	283.41	176.18	107.23		
765	0.41	6.272	53.6	-12.58	-2.23	41.5	20	200	209.95	278.90	173.92	104.98		
758	0.435	6.701	53.1	-13.37	-2.37	41.8	20	200	208.71	277.65	173.30	104.35		
751	0.46	7.129	52.6	-14.16	-2.51	42.0	20.1	201	208.52	277.47	173.21	104.26		
744	0.485	7.558	52.1	-14.95	-2.65	42.3	19.9	199	205.17	274.12	171.53	102.59		
737	0.509	7.969	51.6	-15.73	-2.79	42.5	19.7	197	201.90	270.84	169.90	100.95		
730	0.534	8.397	51.1	-16.52	-2.93	42.8	19.5	195	198.60	267.55	168.25	99.30		
724	0.559	8.826	50.7	-17.24	-3.06	43.0	19.4	194	196.39	265.34	167.15	98.20		
717	0.584	9.254	50.2	-18.03	-3.20	43.3	19.4	194	195.21	264.15	166.55	97.60		
711	0.609	9.683	49.8	-18.75	-3.32	43.6	19.2	192	192.00	260.95	164.95	96.00		
705	0.634	10.111	49.4	-19.47	-3.45	43.8	19.1	191	189.84	258.79	163.87	94.92		
699	0.659	10.540	48.9	-20.19	-3.58	44.1	19.1	191	188.70	257.65	163.30	94.35		
693	0.684	10.968	48.5	-20.91	-3.71	44.3	19.1	191	187.57	256.52	162.73	93.78		
687	0.709	11.396	48.1	-21.63	-3.83	44.6	19	190	185.44	254.39	161.67	92.72		
681	0.734	11.825	47.7	-22.35	-3.96	44.9	19	190	184.32	253.26	161.11	92.16		
675	0.759	12.253	47.3	-23.07	-4.09	45.2	18.9	189	182.21	251.16	160.05	91.11		
669	0.784	12.682	46.8	-23.79	-4.22	45.4	18.9	189	181.10	250.05	159.50	90.55		
663	0.808	13.093	46.4	-24.50	-4.34	45.7	19	190	181.00	249.95	159.45	90.50		
656	0.833	13.522	45.9	-25.29	-4.48	46.0	18.9	189	178.90	247.85	158.40	89.45		
651	0.858	13.950	45.6	-25.94	-4.60	46.3	19	190	178.78	247.73	158.34	89.39		
645	0.883	14.378	45.2	-26.66	-4.72	46.6	19.2	192	179.58	248.53	158.74	89.79		
639	0.908	14.807	44.7	-27.38	-4.85	46.9	19.3	193	179.42	248.37	158.66	89.71		

CD10 Test Results

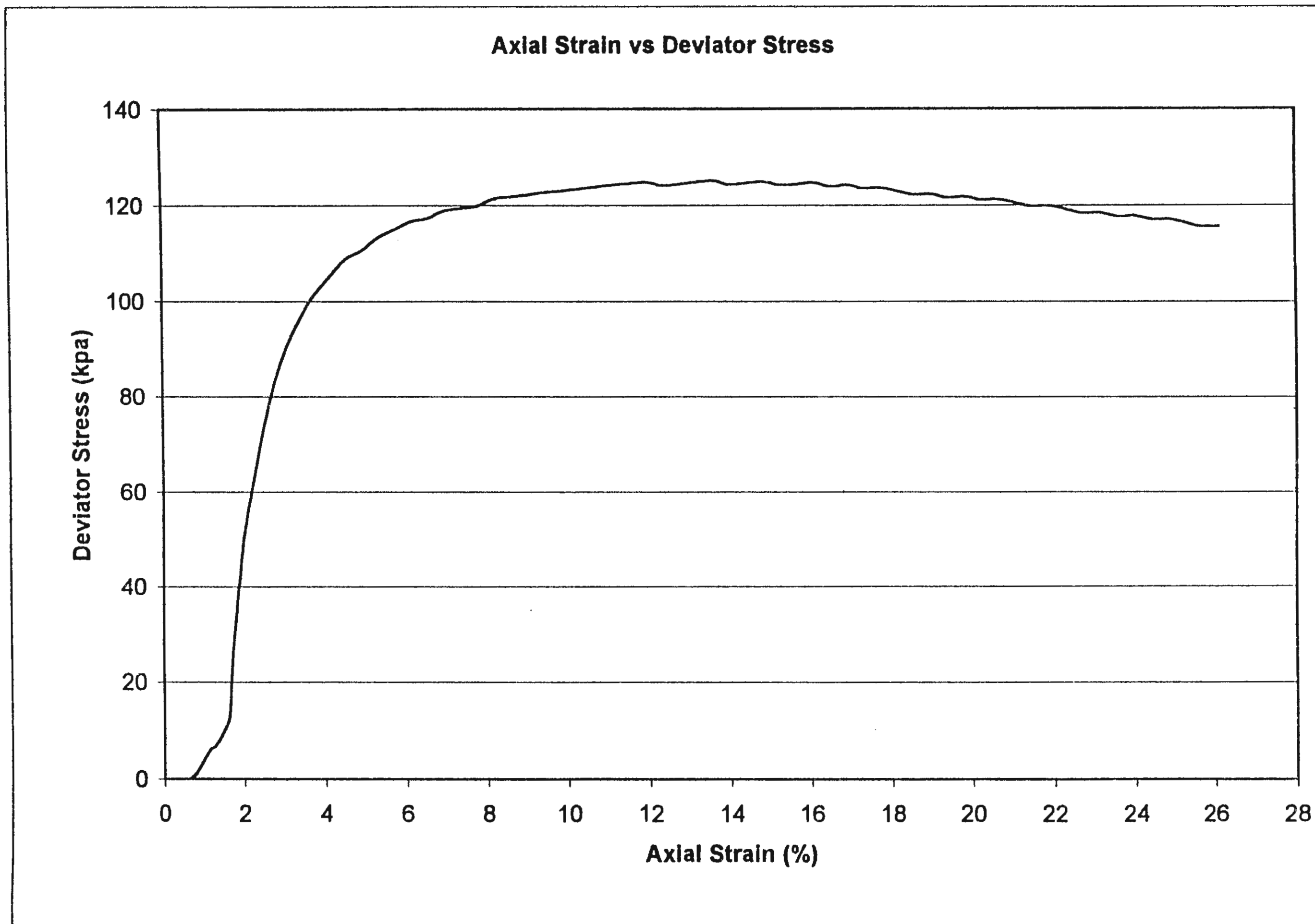
Harrison County

Sample No. 2457/B1/2
Test Date : 10/12/99



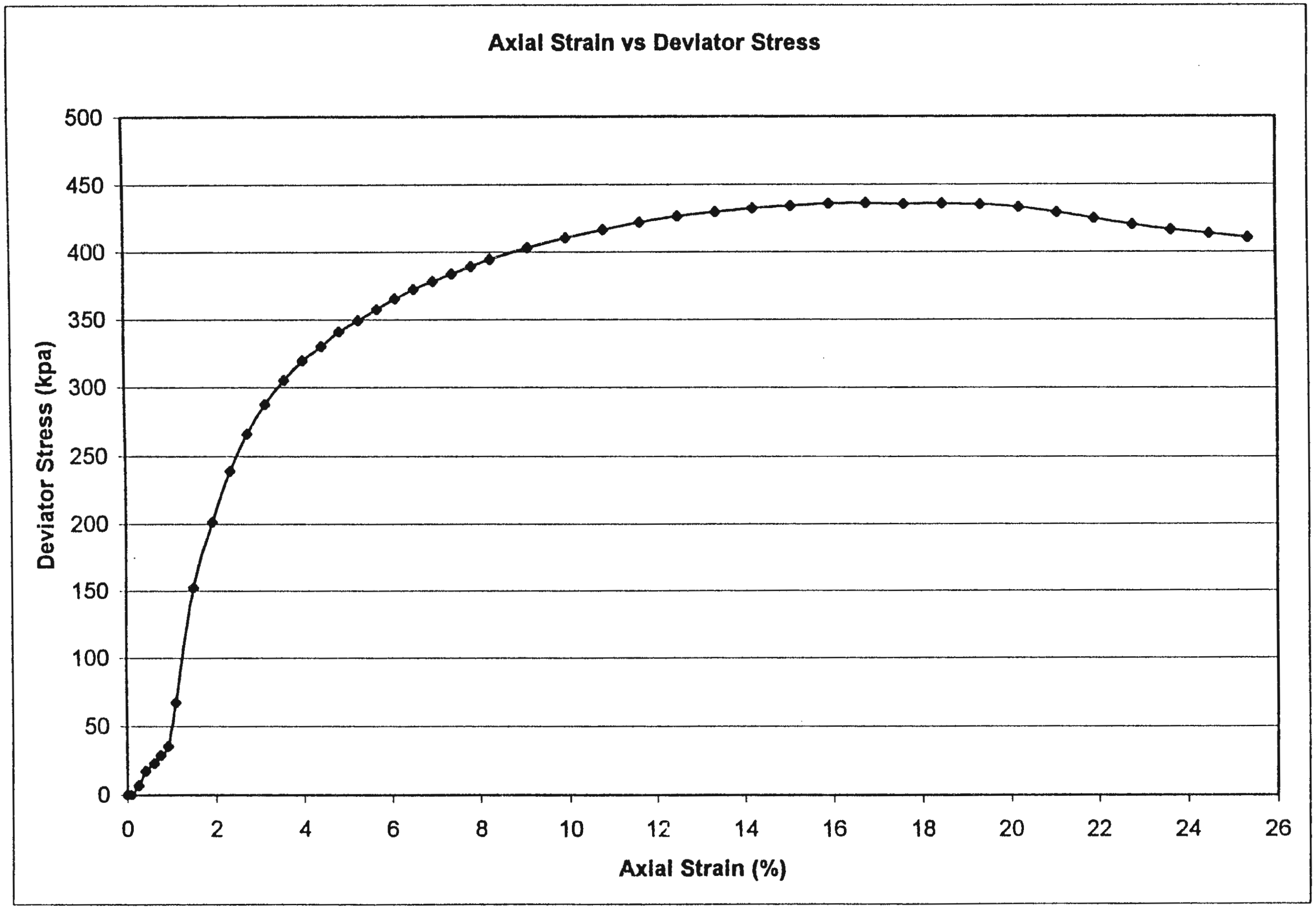
Sample No. 2457/B2/1
Test Date : 10/05/99

	Consolidated-drained test on loess													
	Test No.	1												
	Name	cd10	2457/B2/1											
	Initial	Initial	Initial	Confining	Confining	Bef. Cons	Af. Cons	Bef. Cons	Af. Cons	Void	Dry Unit	Dry Unit	Dry Unit	
	Height	Diamete	Volume	Pressure	Pressure	VC	VC	H	H	Ratio	Weight	Weight	Weight	
	152	71.6	612.01	10	68.95	23.66	68.95	0.009	0.01	ei	(g/cm^3)	(pcf)	(pcf)	
	(mm)	(mm)	(cm^3)	(psi)	(kPa)	(cm^3)	(cm^3)	(in)	(in)	1.214	1.22	76.10	82.19	
				Bef Cons				Aft Cons						
	Specimen	Moistur	Specific	Specimen	Specimen	Specimen	Specimen	Volume	Height	Diameter	Volume	Volume	Void	Dry Unit
	Weight	Content	Gravity	Height	Diameter	Area	Volume	after Cons	after Cons	after Cons	Solid	Voids	Ratio	Weight
	(g)	(%)	(g/cm^3)	(cm)	(cm)	(cm^2)	(cm^3)	(cm^3)	(cm)	(cm)	(cm^3)	(cm^3)	e_0	(g/cm^3)
	985.2	31.99	2.7	15.2	7.16	40.26	612.01	566.72	15.20	6.89	276.45	290.27	1.050	1.32
Reading	Axial	Axial	Volume	Corrected	Volume	Corrected	Axial	Axial	Axial	σ_1	p	q		
	Deflection	Strain	Change	VC	Change	Area	Load	Load	Stress					
	(in)	(%)	(cm^3)	(cm^3)	(%)	(cm^2)		(lb)	(kPa)	(kPa)	(kPa)	(kPa)		
985	0.01	0	69.0	0	0	37.3	0.3	3	0	68.95	68.95	0		
985	0.01	0	69.0	0	0	37.3	0.3	3	0	68.95	68.95	0		
984	0.019	0.15	68.9	-0.18	-0.03	37.4	0.3	3	0	68.95	68.95	0		
984	0.029	0.32	68.9	-0.30	-0.05	37.4	0.3	3	0	68.95	68.95	0		
983	0.038	0.47	68.8	-0.48	-0.08	37.5	0.3	3	0	68.95	68.95	0		
981	0.048	0.64	68.7	-0.74	-0.13	37.6	0.3	3	0	68.95	68.95	0		
980	0.058	0.80	68.6	-0.93	-0.16	37.7	0.4	4	1.18	70.13	69.54	0.59		
979	0.068	0.97	68.5	-1.12	-0.20	37.7	0.6	6	3.54	72.48	70.72	1.77		
978	0.078	1.14	68.5	-1.31	-0.23	37.8	0.8	8	5.88	74.83	71.89	2.94		
978	0.088	1.30	68.5	-1.43	-0.25	37.9	0.9	9	7.05	75.99	72.47	3.52		
977	0.098	1.47	68.4	-1.62	-0.29	38.0	1.1	11	9.38	78.32	73.64	4.69		
977	0.108	1.64	68.4	-1.74	-0.31	38.0	1.4	14	12.87	81.81	75.38	6.43		
978	0.113	1.72	68.5	-1.73	-0.30	38.1	2.4	24	24.54	93.49	81.22	12.27		
980	0.123	1.89	68.6	-1.71	-0.30	38.1	3.8	38	40.84	109.79	89.37	20.42		
983	0.132	2.04	68.8	-1.60	-0.28	38.2	4.8	48	52.44	121.38	95.17	26.22		
989	0.158	2.47	69.2	-1.50	-0.26	38.3	6.5	65	71.94	140.89	104.92	35.97		
993	0.182	2.87	69.5	-1.50	-0.27	38.5	7.7	77	85.51	154.45	111.70	42.75		
996	0.207	3.29	69.7	-1.59	-0.28	38.7	8.5	85	94.33	163.28	116.11	47.16		
998	0.232	3.71	69.9	-1.75	-0.31	38.8	9.1	91	100.76	169.71	119.33	50.38		
998	0.256	4.11	69.9	-2.04	-0.36	39.0	9.5	95	104.85	173.80	121.37	52.43		
998	0.282	4.55	69.9	-2.35	-0.42	39.2	9.9	99	108.86	177.80	123.38	54.43		
998	0.306	4.95	69.9	-2.64	-0.47	39.4	10.1	101	110.60	179.55	124.25	55.30		
998	0.331	5.36	69.9	-2.94	-0.52	39.6	10.4	104	113.43	182.37	125.66	56.71		
998	0.356	5.78	69.9	-3.24	-0.57	39.8	10.6	106	115.10	184.05	126.50	57.55		
998	0.381	6.20	69.9	-3.54	-0.62	40.0	10.8	108	116.75	185.70	127.32	58.38		
997	0.405	6.60	69.8	-3.90	-0.69	40.2	10.9	109	117.29	186.24	127.59	58.64		
996	0.43	7.02	69.7	-4.27	-0.75	40.4	11.1	111	118.89	187.84	128.39	59.44		
994	0.454	7.42	69.6	-4.70	-0.83	40.6	11.2	112	119.38	188.33	128.64	59.69		
992	0.479	7.84	69.4	-5.14	-0.91	40.8	11.3	113	119.84	188.79	128.87	59.92		
990	0.504	8.26	69.3	-5.58	-0.98	41.0	11.5	115	121.37	190.32	129.63	60.69		
988	0.529	8.67	69.2	-6.02	-1.06	41.3	11.6	116	121.81	190.75	129.85	60.90		
986	0.554	9.09	69.0	-6.46	-1.14	41.5	11.7	117	122.23	191.18	130.06	61.11		
984	0.579	9.51	68.9	-6.90	-1.22	41.7	11.8	118	122.64	191.59	130.27	61.32		
981	**0.604**	**9.93**	**68.7**	**-7.41**	**-1.31**	**41.9**	**11.9**	**119**	123.03	**191.97**	**130.46**	**61.51**		
978	0.629	10.35	68.5	-7.92	-1.40	42.2	12	120	123.40	192.35	130.65	61.70		
976	0.654	10.76	68.3	-8.36	-1.47	42.4	12.1	121	123.78	192.73	130.84	61.89		
973	0.678	11.16	68.1	-8.86	-1.56	42.6	12.2	122	124.16	193.11	131.03	62.08		
970	0.703	11.58	67.9	-9.37	-1.65	42.9	12.3	123	124.51	193.45	131.20	62.25		
968	0.728	12.00	67.8	-9.81	-1.73	43.1	12.4	124	124.85	193.80	131.37	62.43		
964	0.753	12.42	67.5	-10.39	-1.83	43.4	12.4	124	124.14	193.08	131.02	62.07		
961	0.778	12.84	67.3	-10.90	-1.92	43.6	12.5	125	124.46	193.40	131.18	62.23		
958	0.802	13.24	67.1	-11.39	-2.01	43.8	12.6	126	124.79	193.74	131.34	62.40		
955	0.827	13.65	66.9	-11.90	-2.10	44.1	12.7	127	125.09	194.04	131.49	62.54		
951	0.852	14.07	66.6	-12.48	-2.20	44.4	12.7	127	124.36	193.31	131.13	62.18		
948	0.877	14.49	66.4	-12.99	-2.29	44.6	12.8	128	124.64	193.59	131.27	62.32		
945	0.902	14.91	66.2	-13.50	-2.38	44.9	12.9	129	124.92	193.86	131.41	62.46		
941	0.926	15.31	65.9	-14.07	-2.48	45.1	12.9	129	124.21	193.15	131.05	62.10		
938	0.952	15.74	65.7	-14.59	-2.58	45.4	13	130	124.44	193.38	131.17	62.22		
934	0.976	16.15	65.4	-15.16	-2.68	45.7	13.1	131	124.70	193.65	131.30	62.35		
930	1.001	16.56	65.1	-15.74	-2.78	45.9	13.1	131	123.95	192.90	130.92	61.98		
926	1.026	16.98	64.8	-16.32	-2.88	46.2	13.2	132	124.17	193.12	131.03	62.09		
923	1.05	17.38	64.6	-16.82	-2.97	46.5	13.2	132	123.47	192.41	130.68	61.73		
919	1.076	17.82	64.3	-17.41	-3.07	46.8	13.3	133	123.64	192.59	130.77	61.82		
915	1.101	18.23	64.1	-17.99	-3.17	47.1	13.3	133	122.89	191.84	130.39	61.45		
911	1.126	18.65	63.8	-18.57	-3.28	47.3	13.3	133	122.14	191.09	130.02	61.07		
907	1.151	19.07	63.5	-19.15	-3.38	47.6	13.4	134	122.33	191.28	130.11	61.17		
903	1.175	19.47	63.2	-19.72	-3.48	47.9	13.4	134	121.61	190.55	129.75	60.80		
899	1.2	19.89	62.9	-20.30	-3.58	48.2	13.5	135	121.78	190.73	129.84	60.89		
895	1.225	20.31	62.7	-20.88	-3.68	48.5	13.5	135	121.02	189.97	129.46	60.51		
891	1.25	20.72	62.4	-21.46	-3.79	48.8	13.6	136	121.18	190.13	129.54	60.59		
887	1.275	21.14	62.1	-22.04	-3.89	49.1	13.6	136	120.42	189.37	129.16	60.21		


Axial Strain vs Deviator Stress
Deviator Stress (kpa)
140
120
100
80
60
40
20
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
Axial Strain (%)

Sample No. 2457/B2/2
Test Date : 10/06/99

	Consolidated-drained test on loess													
	Test No.	2												
	Name	cd30	2457/B2/2											
	Initial	Initial	Initial	Confining	Confining	Bef. Cons	Af. Cons	Bef. Cons	Af. Cons	Void	Dry Unit	Dry Unit	Dry Unit	
	Height	Diamete	Volume	Pressure	Pressure	VC	VC	H	H	Ratio	Weight	Weight	Weight	
	149	71.6	599.93	30	206.84	44.87	75.11	0.015	0.06	ei	(g/cm^3)	(pcf)	(pcf)	
	(mm)	(mm)	(cm^3)	(psi)	(kPa)	(cm^3)	(cm^3)	(in)	(in)	1.206	1.22	76.36	80.41	
				Bef Cons				Aft Cons						
	Specimen	Moistur	Specific	Specimen	Specimen	Specimen	Specimen	Volume	Height	Diameter	Volume	Volume	Void	Dry Unit
	Weight	Content	Gravity	Height	Diameter	Area	Volume	after Cons	after Cons	after Cons	Solid	Voids	Ratio	Weight
	(g)	(%)	(g/cm^3)	(cm)	(cm)	(cm^2)	(cm^3)	(cm^3)	(cm)	(cm)	(cm^3)	(cm^3)	e_0	(g/cm^3)
	960.7	30.86	2.7	14.9	7.16	40.26	599.93	569.69	14.79	7.00	271.90	297.79	1.10	1.29
Reading	Axial	Axial	Volume	Corrected	Volume	Corrected	Axial	Axial	Axial	σ_1	p	q		
	Deflection	Strain	Change	VC	Change	Area	Load	Load	Stress					
	(in)	(%)	(cm^3)	(cm^3)	(%)	(cm^2)		(lb)	(kPa)	(kPa)	(kPa)	(kPa)		
1073	0.06	0	75.1	0	0	38.5	0.3	3	0	206.84	206.84	0		
1073	0.059	-0.017	75.1	0.01	0.00	38.5	0.2	2	-1.15	205.69	206.27	-0.58		
1073	0.059	-0.017	75.1	0.01	0.00	38.5	0.2	2	-1.15	205.69	206.27	-0.58		
1072	0.065	0.086	75.0	-0.13	-0.02	38.6	0.3	3	0	206.84	206.84	0		
1072	0.075	0.258	75.0	-0.25	-0.04	38.6	0.9	9	6.91	213.75	210.30	3.45		
1070	0.084	0.412	74.9	-0.50	-0.09	38.7	1.8	18	17.23	224.07	215.46	8.62		
1070	0.095	0.601	74.9	-0.63	-0.11	38.8	2.3	23	22.93	229.77	218.31	11.46		
1069	0.104	0.756	74.8	-0.81	-0.14	38.9	2.8	28	28.60	235.45	221.14	14.30		
1069	0.114	0.928	74.8	-0.93	-0.16	39.0	3.4	34	35.40	242.24	224.54	17.70		
1069	0.124	1.099	74.8	-1.05	-0.18	39.0	6.2	62	67.24	274.08	240.46	33.62		
1078	0.148	1.512	75.5	-0.71	-0.12	39.2	13.7	137	152.17	359.02	282.93	76.09		
1089	0.173	1.941	76.2	-0.24	-0.04	39.3	18.1	181	201.43	408.27	307.56	100.71		
1098	0.197	2.353	76.9	0.11	0.02	39.5	21.5	215	239.03	445.88	326.36	119.52		
1106	0.221	2.766	77.4	0.38	0.07	39.6	24	240	266.22	473.06	339.95	133.11		
1112	0.245	3.178	77.8	0.51	0.09	39.8	26	260	287.53	494.37	350.61	143.77		
1119	0.27	3.608	78.3	0.70	0.12	39.9	27.7	277	305.29	512.13	359.49	152.65		
1124	0.295	4.037	78.7	0.75	0.13	40.1	29.1	291	319.49	526.33	366.59	159.74		
1129	0.32	4.466	79.0	0.80	0.14	40.3	30.2	302	330.24	537.08	371.96	165.12		
1133	0.344	4.879	79.3	0.79	0.14	40.4	31.3	313	340.90	547.75	377.29	170.45		
1136	0.369	5.308	79.5	0.70	0.12	40.6	32.2	322	349.16	556.00	381.42	174.58		
1140	0.394	5.738	79.8	0.68	0.12	40.8	33.1	331	357.37	564.21	385.53	178.69		
1142	0.418	6.150	79.9	0.53	0.09	41.0	34	340	365.48	572.32	389.58	182.74		
1144	0.443	6.579	80.1	0.37	0.07	41.2	34.8	348	372.34	579.18	393.01	186.17		
1146	0.468	7.009	80.2	0.21	0.04	41.4	35.5	355	378.04	584.88	395.86	189.02		
1147	0.493	7.438	80.3	-0.02	0.00	41.6	36.2	362	383.62	590.46	398.65	191.81		
1148	0.518	7.868	80.4	-0.25	-0.04	41.8	36.9	369	389.13	595.97	401.41	194.56		
1148	0.543	8.297	80.4	-0.55	-0.10	42.1	37.6	376	394.51	601.36	404.10	197.26		
1148	0.592	9.139	80.4	-1.13	-0.20	42.5	38.8	388	403.05	609.90	408.37	201.53		
1148	**0.642**	**9.998**	**80.4**	**-1.73**	**-0.30**	**42.9**	**39.9**	**399**	410.22	**617.06**	**411.95**	**205.11**		
1148	0.692	10.857	80.4	-2.33	-0.41	43.4	40.9	409	416.13	622.97	414.91	208.06		
1148	0.741	11.699	80.4	-2.92	-0.51	43.9	41.9	419	421.92	628.76	417.80	210.96		
1144	0.791	12.558	80.1	-3.80	-0.67	44.4	42.8	428	426.20	633.04	419.94	213.10		
1140	0.841	13.417	79.8	-4.68	-0.82	44.9	43.6	436	429.29	636.14	421.49	214.65		
1135	0.89	14.258	79.5	-5.62	-0.99	45.4	44.4	444	432.27	639.11	422.98	216.13		
1130	0.94	15.117	79.1	-6.57	-1.15	45.9	45.1	451	434.02	640.86	423.85	217.01		
1124	0.99	15.976	78.7	-7.59	-1.33	46.5	45.8	458	435.57	642.41	424.63	217.78		
1117	1.039	16.818	78.2	-8.67	-1.52	47.0	46.4	464	436.07	642.92	424.88	218.04		
1110	1.089	17.677	77.7	-9.76	-1.71	47.6	46.9	469	435.43	642.27	424.56	217.72		
1104	1.139	18.536	77.3	-10.78	-1.89	48.2	47.5	475	435.67	642.51	424.68	217.83		
1097	1.189	19.395	76.8	-11.87	-2.08	48.8	48	480	434.83	641.67	424.26	217.41		
1089	1.239	20.254	76.2	-13.03	-2.29	49.4	48.4	484	432.94	639.78	423.31	216.47		
1081	1.289	21.113	75.7	-14.19	-2.49	50.1	48.6	486	429.20	636.04	421.44	214.60		
1073	1.338	21.954	75.1	-15.34	-2.69	50.7	48.7	487	424.66	631.51	419.17	212.33		
1066	1.388	22.813	74.6	-16.43	-2.88	51.4	48.8	488	420.07	626.92	416.88	210.04		
1059	1.438	23.672	74.1	-17.52	-3.07	52.0	49	490	416.34	623.18	415.01	208.17		
1052	1.488	24.531	73.6	-18.61	-3.27	52.7	49.3	493	413.42	620.26	413.55	206.71		
1045	1.538	25.390	73.2	-19.70	-3.46	53.4	49.6	496	410.46	617.30	412.07	205.23		


Axial Strain vs Deviator Stress
500
450
400
350
300
250
200
150
100
50
0
Deviator Stress (kpa)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
Axial Strain (%)

Consolidated-drained test on loess

NOTE : MEMBRANE LEAK!!!!

Test No.	8	
Name	cd20	2457/B3/2

Initial Height	Initial Diamete	Initial Volume	Confining Pressure	Confining Pressure	Bef. Cons VC	Af. Cons VC	Bef. Cons H	Af. Cons H	Void Ratio	Dry Unit Weight	Dry Unit Weight	Dry Unit Weight
154	70.3	597.75	20	137.90	30.03	93.17	0.02	0.022	ei	(g/cm^3)	(pcf)	(pcf)
(mm)	(mm)	(cm^3)	(psi)	(kPa)	(cm^3)	(cm^3)	(in)	(in)	1.097	1.29	80.36	89.85

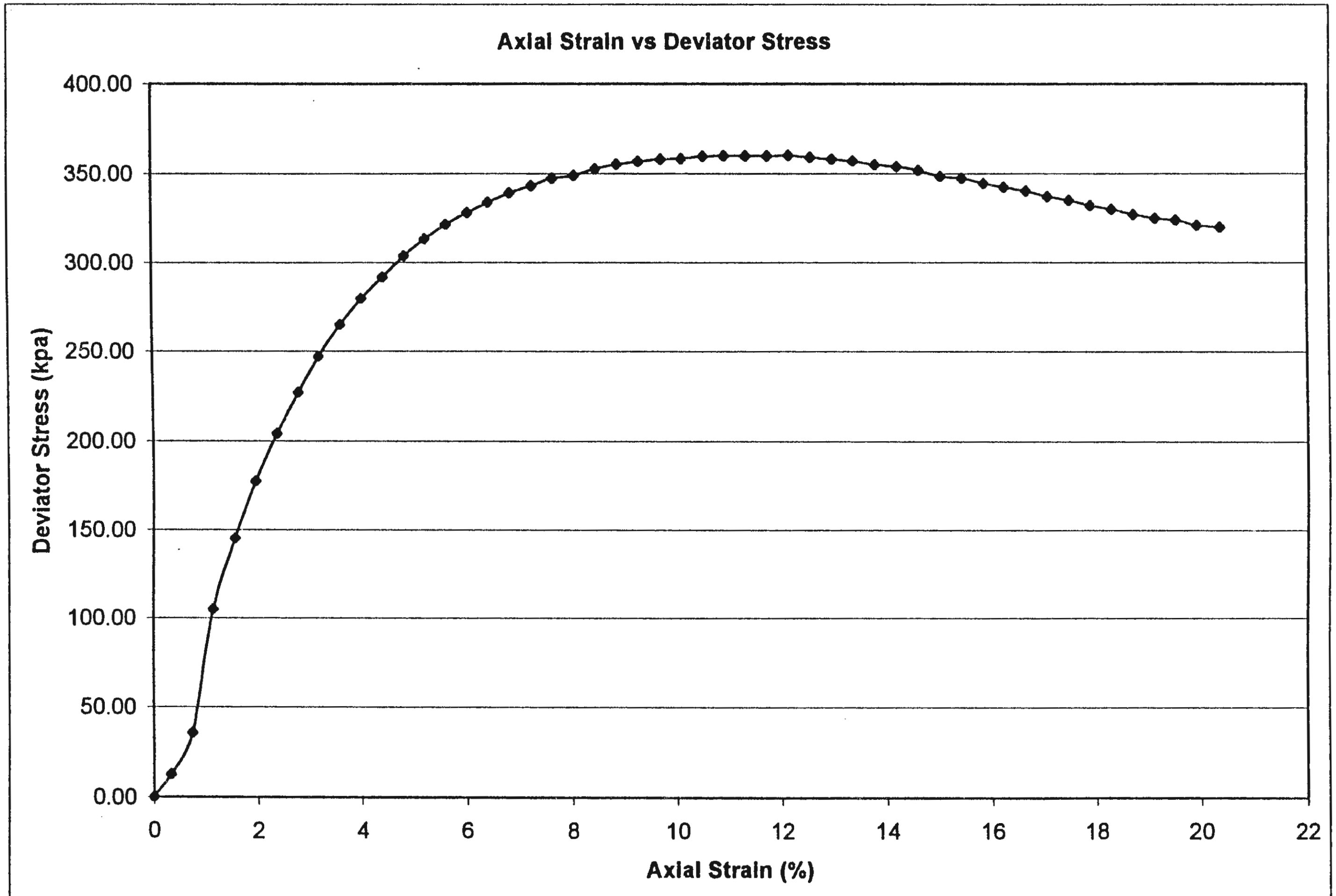
			Bef Cons				Aft Cons						
Specimen Weight (g)	Moistur Content (%)	Specific Gravity (g/cm^3)	Specimen Height (cm)	Specimen Diameter (cm)	Specimen Area (cm^2)	Specimen Volume (cm^3)	Volume after Cons (cm^3)	Height after Cons (cm)	Diameter after Cons (cm)	Volume Solid (cm^3)	Volume Voids (cm^3)	Void Ratio e_o	Dry Unit Weight (g/cm^3)
1010.5	31.27	2.7	15.4	7.03	38.82	597.75	534.61	15.39	6.65	285.11	249.51	0.875	1.44

Reading	Axial Deflection (in)	Axial Strain (%)	Volume Change (cm^3)	Corrected VC (cm^3)	Volume Change (%)	Corrected Area (cm^2)	Axial Load	Axial Load (lb)	Axial Stress (kPa)	σ_1 (kPa)	p (kPa)	q (kPa)
1333	0.025	0	93.3	0	0	34.7	0.1	1	0.00	137.90	137.90	0
1334	0.024	-0.016	93.4	0.08	0.02	34.7	0.1	1	0.00	137.90	137.90	0.00
1334	0.045	0.330	93.4	-0.17	-0.03	34.9	1.1	11	12.76	150.66	144.28	6.38
1334	0.07	0.742	93.4	-0.47	-0.09	35.0	2.9	29	35.57	173.46	155.68	17.78421
1343	0.094	1.138	94.0	-0.13	-0.02	35.1	8.4	84	105.08	242.98	190.44	52.54
1354	0.119	1.551	94.8	0.34	0.06	35.3	11.6	116	145.11	283.01	210.45	72.56
1363	0.143	1.947	95.4	0.68	0.13	35.4	14.2	142	177.32	315.22	226.56	88.66
1371	0.168	2.359	96.0	0.94	0.18	35.5	16.4	164	204.23	342.12	240.01	102.11
1376	0.193	2.772	96.3	0.99	0.19	35.7	18.3	183	227.09	364.98	251.44	113.54
1381	0.217	3.168	96.7	1.06	0.20	35.8	20	200	247.32	385.21	261.55	123.66
1385	0.242	3.580	97.0	1.04	0.19	35.9	21.5	215	264.82	402.71	270.30	132.41
1386	0.267	3.993	97.0	0.81	0.15	36.1	22.8	228	279.58	417.48	277.69	139.79
1387	0.292	4.405	97.1	0.58	0.11	36.3	23.9	239	291.75	429.64	283.77	145.87
1387	0.317	4.818	97.1	0.28	0.05	36.5	25	250	303.74	441.64	289.77	151.87
1388	0.341	5.214	97.2	0.06	0.01	36.6	25.9	259	313.28	451.18	294.54	156.64
1387	0.366	5.626	97.1	-0.31	-0.06	36.8	26.7	267	321.37	459.26	298.58	160.68
1387	0.391	6.039	97.1	-0.61	-0.11	37.0	27.4	274	328.20	466.10	302.00	164.10
1386	0.415	6.435	97.0	-0.97	-0.18	37.2	28	280	333.78	471.67	304.78	166.89
1383	0.44	6.847	96.8	-1.48	-0.28	37.4	28.6	286	339.13	477.02	307.46	169.56
1381	0.465	7.260	96.7	-1.92	-0.36	37.6	29.1	291	343.27	481.16	309.53	171.63
1377	0.489	7.656	96.4	-2.49	-0.47	37.8	29.6	296	347.33	485.22	311.56	173.66
1373	0.514	8.068	96.1	-3.07	-0.57	38.0	29.9	299	348.92	486.81	312.35	174.46
1369	0.539	8.480	95.8	-3.65	-0.68	38.2	30.4	304	352.80	490.69	314.29	176.40
1364	0.564	8.893	95.5	-4.30	-0.80	38.4	30.8	308	355.42	493.31	315.60	177.71
1360	0.589	9.305	95.2	-4.88	-0.91	38.6	31.1	311	356.88	494.78	316.34	178.44
1355	0.615	9.734	94.9	-5.54	-1.04	38.9	31.4	314	358.19	496.09	316.99	179.10
1349	0.639	10.130	94.4	-6.25	-1.17	39.1	31.6	316	358.43	496.32	317.11	179.21
1344	0.664	10.543	94.1	-6.90	-1.29	39.3	31.9	319	359.75	497.64	317.77	179.87
1339	0.688	10.939	93.7	-7.54	-1.41	39.5	32.1	321	359.98	497.88	317.89	179.99
1333	0.713	11.351	93.3	-8.26	-1.54	39.8	32.3	323	360.08	497.97	317.93	180.04
1327	0.738	11.764	92.9	-8.98	-1.68	40.0	32.5	325	360.15	498.05	317.97	180.08
1322	**0.763**	**12.176**	**92.5**	**-9.63**	**-1.80**	**40.3**	**32.7**	**327**	360.25	**498.15**	**318.02**	**180.13**
1316	0.788	12.589	92.1	-10.35	-1.94	40.5	32.8	328	359.18	497.08	317.49	179.59
1310	0.813	13.001	91.7	-11.07	-2.07	40.7	32.9	329	358.11	496.00	316.95	179.05
1305	0.837	13.397	91.4	-11.70	-2.19	41.0	33	330	357.15	495.04	316.47	178.57
1299	0.862	13.810	90.9	-12.42	-2.32	41.2	33	330	354.98	492.87	315.38	177.49
1294	0.887	14.222	90.6	-13.07	-2.45	41.5	33.1	331	353.93	491.83	314.86	176.97
1288	0.912	14.635	90.2	-13.79	-2.58	41.7	33.1	331	351.77	489.66	313.78	175.88
1282	0.937	15.047	89.7	-14.51	-2.71	42.0	33	330	348.55	486.45	312.17	174.28
1277	0.962	15.460	89.4	-15.16	-2.84	42.2	33.1	331	347.50	485.40	311.65	173.75
1272	0.987	15.872	89.0	-15.81	-2.96	42.5	33	330	344.35	482.25	310.07	172.18
1267	1.01	16.251	88.7	-16.44	-3.08	42.7	33	330	342.41	480.30	309.10	171.20
1262	1.036	16.680	88.3	-17.10	-3.20	43.0	33	330	340.25	478.14	308.02	170.12
1256	1.061	17.093	87.9	-17.82	-3.33	43.3	32.9	329	337.09	474.99	306.44	168.55
1252	1.086	17.505	87.6	-18.40	-3.44	43.5	32.9	329	335.06	472.96	305.43	167.53
1246	1.111	17.918	87.2	-19.12	-3.58	43.8	32.8	328	331.94	469.83	303.86	165.97
1242	1.136	18.330	86.9	-19.70	-3.69	44.1	32.8	328	329.93	467.82	302.86	164.96
1238	1.161	18.743	86.7	-20.28	-3.79	44.4	32.7	327	326.91	464.81	301.35	163.46
1234	1.186	19.155	86.4	-20.86	-3.90	44.6	32.7	327	324.91	462.81	300.35	162.46
1230	1.21	19.551	86.1	-21.43	-4.01	44.9	32.8	328	323.98	461.88	299.89	161.99
1225	1.234	19.947	85.8	-22.07	-4.13	45.2	32.7	327	321.03	458.93	298.41	160.52
1222	1.26	20.376	85.5	-22.59	-4.23	45.5	32.8	328	319.99	457.89	297.89	160.00

CD10 Test Results

Harrison County

Sample No. 2457/B3/2
Test Date : 10/13/99



Consolidated-drained test on loess

Test No.	10											
Name	cd20	2457/B4/2										
Initial Height	Initial Diamete	Initial Volume	Confining Pressure	Confining Pressure	Bef. Cons VC	Af. Cons VC	Bef. Cons H	Af. Cons H	Void Ratio	Dry Unit Weight	Dry Unit Weight	Dry Unit Weight
141	71.5	566.14	20	137.90	35.14	90.93	0.001	0.033	ei	(g/cm^3)	(pcf)	(pcf)
(mm)	(mm)	(cm^3)	(psi)	(kPa)	(cm^3)	(cm^3)	(in)	(in)	1.049	1.32	82.22	91.21

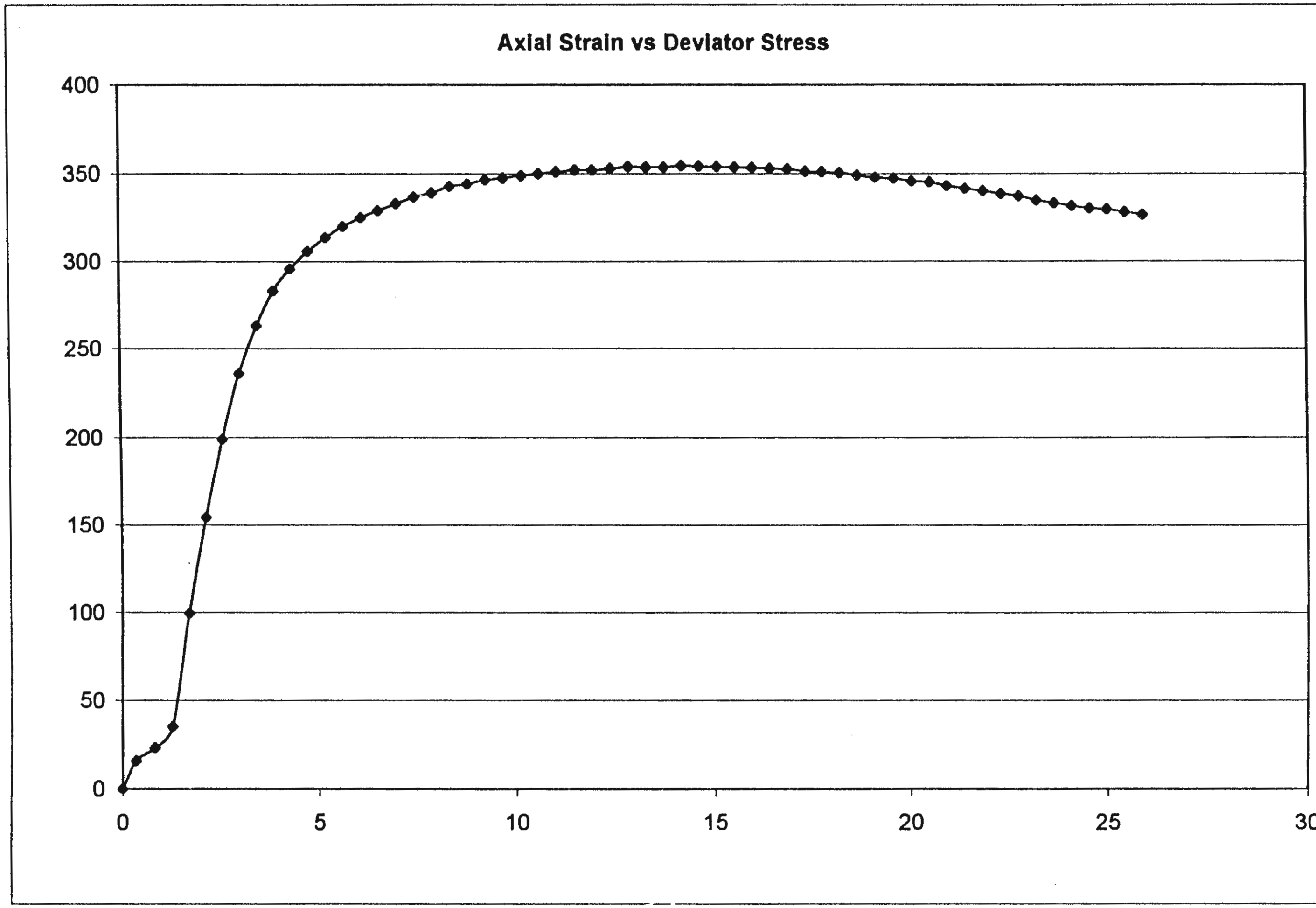
			Bef Cons				Aft Cons						
Specimen Weight (g)	Moistur Content (%)	Specific Gravity (g/cm^3)	Specimen Height (cm)	Specimen Diameter (cm)	Specimen Area (cm^2)	Specimen Volume (cm^3)	Volume after Cons (cm^3)	Height after Cons (cm)	Diameter after Cons (cm)	Volume Solid (cm^3)	Volume Voids (cm^3)	Void Ratio e_o	Dry Unit Weight (g/cm^3)
875.2	17.32	2.7	14.1	7.15	40.15	566.14	510.35	14.02	6.81	276.29	234.05	0.847	1.46

Reading	Axial Deflection (in)	Axial Strain (%)	Volume Change (cm^3)	Corrected VC (cm^3)	Volume Change (%)	Corrected Area (cm^2)	Axial Load	Axial Load (lb)	Axial Stress (kPa)	σ_1 (kPa)	p (kPa)	q (kPa)
1299	0.033	0	90.9	0	0	36.4	0.1	1	0	137.90	137.90	0
1298	0.052	0.344	90.9	-0.30	-0.06	36.6	1.4	14	15.82	153.72	145.81	7.91
1296	0.078	0.815	90.7	-0.75	-0.15	36.8	2	20	22.99	160.89	149.39	11.50
1295	0.103	1.268	90.7	-1.12	-0.22	37.0	3	30	34.91	172.80	155.35	17.45429
1302	0.127	1.703	91.1	-0.92	-0.18	37.1	8.4	84	99.51	237.41	187.65	49.76
1313	0.151	2.138	91.9	-0.44	-0.09	37.2	13	130	154.12	292.02	214.96	77.06
1323	0.175	2.573	92.6	-0.02	0.00	37.4	16.8	168	198.80	336.69	237.29	99.40
1330	0.2	3.026	93.1	0.17	0.03	37.5	20	200	235.87	373.77	255.83	117.94
1335	0.225	3.479	93.5	0.22	0.04	37.7	22.4	224	263.11	401.01	269.45	131.56
1339	0.249	3.914	93.7	0.21	0.04	37.9	24.2	242	283.06	420.96	279.43	141.53
1340	0.273	4.348	93.8	-0.01	0.00	38.1	25.4	254	295.69	433.58	285.74	147.84
1342	0.298	4.801	93.9	-0.17	-0.03	38.3	26.4	264	305.82	443.72	290.81	152.91
1342	0.323	5.254	93.9	-0.47	-0.09	38.5	27.2	272	313.44	451.34	294.62	156.72
1342	0.347	5.689	93.9	-0.76	-0.15	38.7	27.9	279	319.88	457.78	297.84	159.94
1342	0.372	6.142	93.9	-1.06	-0.21	38.9	28.5	285	325.03	462.92	300.41	162.51
1342	0.396	6.577	93.9	-1.35	-0.26	39.1	29	290	329.03	466.93	302.41	164.52
1342	0.421	7.030	93.9	-1.65	-0.32	39.3	29.5	295	332.91	470.80	304.35	166.45
1341	0.446	7.483	93.9	-2.02	-0.40	39.5	30	300	336.67	474.57	306.23	168.34
1340	0.471	7.936	93.8	-2.39	-0.47	39.7	30.4	304	339.26	477.16	307.53	169.63
1339	0.496	8.389	93.7	-2.76	-0.54	40.0	30.9	309	342.92	480.81	309.35	171.46
1337	0.521	8.842	93.6	-3.20	-0.63	40.2	31.2	312	344.25	482.15	310.02	172.13
1334	0.546	9.295	93.4	-3.71	-0.73	40.4	31.6	316	346.60	484.50	311.20	173.30
1331	0.571	9.748	93.2	-4.22	-0.83	40.7	31.9	319	347.81	485.70	311.80	173.90
1328	0.596	10.201	93.0	-4.73	-0.93	40.9	32.2	322	348.98	486.88	312.39	174.49
1325	0.62	10.636	92.8	-5.22	-1.02	41.2	32.5	325	350.20	488.10	313.00	175.10
1321	0.645	11.089	92.5	-5.80	-1.14	41.4	32.8	328	351.26	489.15	313.52	175.63
1317	0.671	11.560	92.2	-6.40	-1.25	41.7	33.1	331	352.20	490.09	313.99	176.10
1313	0.695	11.995	91.9	-6.96	-1.36	41.9	33.3	333	352.20	490.10	314.00	176.10
1309	0.72	12.447	91.6	-7.54	-1.48	42.2	33.6	336	353.16	491.05	314.47	176.58
1306	0.745	12.900	91.4	-8.05	-1.58	42.5	33.9	339	354.13	492.02	314.96	177.06
1301	0.77	13.353	91.1	-8.70	-1.71	42.7	34.1	341	353.93	491.82	314.86	176.96
1296	0.795	13.806	90.7	-9.35	-1.83	43.0	34.3	343	353.71	491.60	314.75	176.85
1292	0.82	14.259	90.4	-9.93	-1.95	43.3	34.6	346	354.54	492.43	315.16	177.27
1288	**0.844**	**14.694**	**90.2**	**-10.50**	**-2.06**	**43.6**	**34.8**	**348**	354.40	**492.29**	**315.09**	**177.20**
1283	0.869	15.147	89.8	-11.15	-2.19	43.8	35	350	354.11	492.00	314.95	177.05
1279	0.894	15.600	89.5	-11.73	-2.30	44.1	35.2	352	353.84	491.74	314.82	176.92
1273	0.919	16.053	89.1	-12.45	-2.44	44.4	35.4	354	353.46	491.35	314.62	176.73
1269	0.944	16.506	88.8	-13.03	-2.55	44.7	35.6	356	353.15	491.05	314.47	176.58
1264	0.969	16.959	88.5	-13.68	-2.68	45.0	35.8	358	352.78	490.67	314.28	176.39
1260	0.994	17.412	88.2	-14.26	-2.79	45.3	35.9	359	351.45	489.34	313.62	175.72
1254	1.018	17.847	87.8	-14.97	-2.93	45.6	36.1	361	351.08	488.97	313.43	175.54
1249	1.043	18.300	87.4	-15.62	-3.06	45.9	36.3	363	350.65	488.54	313.22	175.32
1244	1.068	18.753	87.1	-16.27	-3.19	46.2	36.4	364	349.23	487.13	312.51	174.62
1240	1.093	19.206	86.8	-16.85	-3.30	46.5	36.5	365	347.86	485.75	311.83	173.93
1234	1.118	19.659	86.4	-17.57	-3.44	46.9	36.7	367	347.34	485.23	311.56	173.67
1230	1.143	20.112	86.1	-18.15	-3.56	47.2	36.8	368	345.94	483.84	310.87	172.97
1225	1.168	20.565	85.8	-18.80	-3.68	47.5	37	370	345.43	483.32	310.61	172.71
1219	1.192	20.999	85.3	-19.51	-3.82	47.8	37	370	343.08	480.97	309.43	171.54
1214	1.217	21.452	85.0	-20.16	-3.95	48.2	37.1	371	341.62	479.51	308.70	170.81
1209	1.242	21.905	84.6	-20.81	-4.08	48.5	37.2	372	340.15	478.04	307.97	170.07
1204	1.267	22.358	84.3	-21.46	-4.20	48.9	37.3	373	338.67	476.57	307.23	169.34
1199	1.292	22.811	83.9	-22.11	-4.33	49.2	37.4	374	337.19	475.09	306.49	168.59
1194	1.317	23.264	83.6	-22.76	-4.46	49.6	37.4	374	334.80	472.70	305.30	167.40
1189	1.342	23.717	83.2	-23.41	-4.59	49.9	37.5	375	333.31	471.21	304.55	166.66
1184	1.367	24.170	82.9	-24.06	-4.71	50.3	37.6	376	331.81	469.71	303.80	165.91
1179	1.392	24.623	82.5	-24.71	-4.84	50.6	37.7	377	330.31	468.21	303.05	165.16
1174	1.416	25.058	82.2	-25.35	-4.97	51.0	37.9	379	329.76	467.65	302.77	164.88
1169	1.441	25.511	81.8	-26.00	-5.09	51.4	38	380	328.23	466.13	302.01	164.12
1165	1.466	25.964	81.6	-26.58	-5.21	51.7	38.1	381	326.75	464.64	301.27	163.37

CD10 Test Results

Harrison County

Sample No. 2457/B4/2
Test Date : 10/13/99



CD30 Test Results

Harrison County

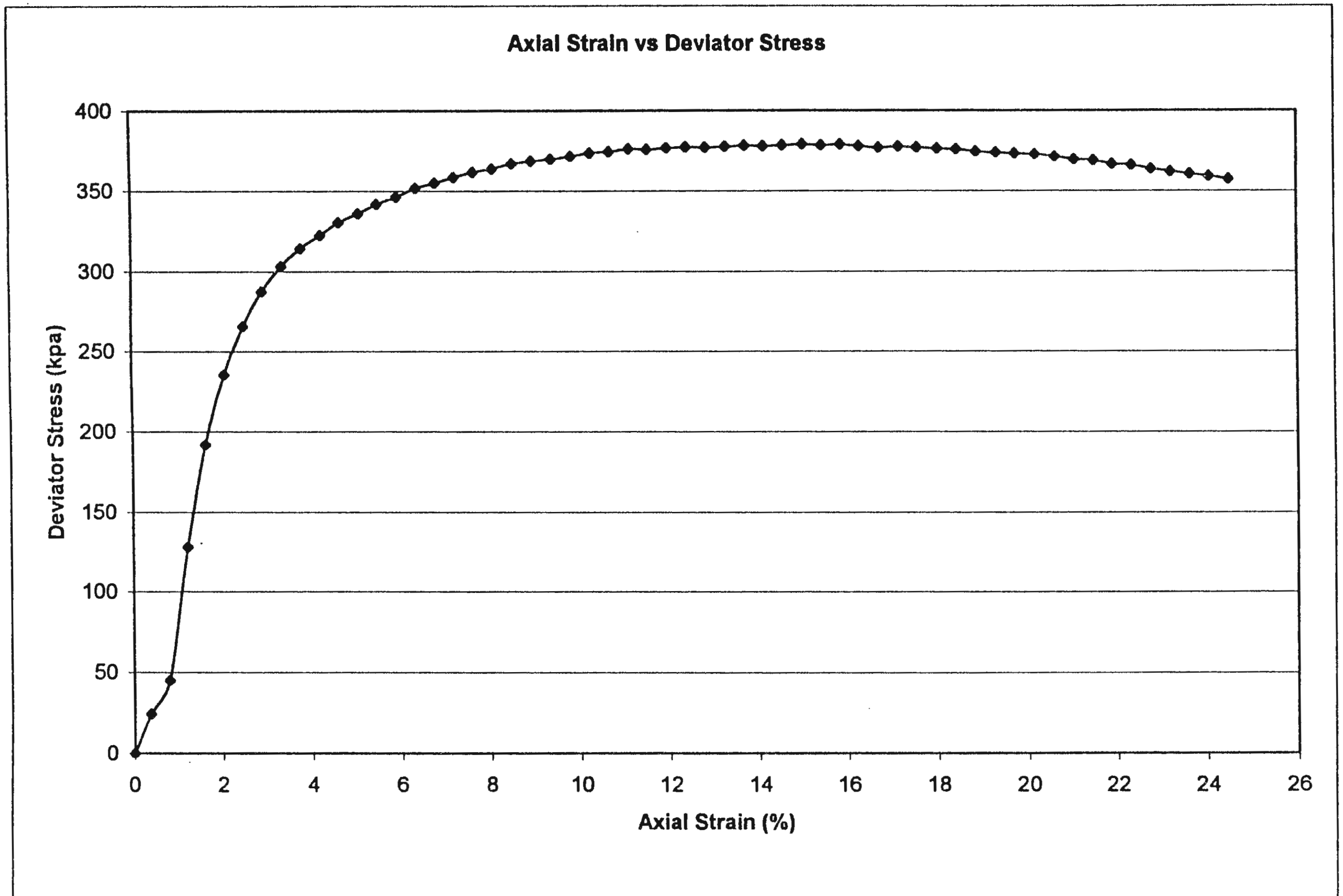
Sample No. 2457/B5/2
Test Date : 10/13/99

	Consolidated-drained test on loess													
	Test No.	6												
	Name	cd30	2457/B5/2											
	Initial Height	Initial Diamete	Initial Volume	Confining Pressure	Confining Pressure	Bef. Cons VC	Af. Cons VC	Bef. Cons H	Af. Cons H	Void Ratio	Dry Unit Weight	Dry Unit Weight	Dry Unit Weight	
	147	73	615.25	30	206.84	20.44	49.28	0.002	0.041	ei	(g/cm^3)	(pcf)	(pcf)	
	(mm)	(mm)	(cm^3)	(psi)	(kPa)	(cm^3)	(cm^3)	(in)	(in)	1.153	1.25	78.24	82.09	
				Bef Cons				Aft Cons						
	Specimen Weight	Moistur Content	Specific Gravity	Specimen Height	Specimen Diameter	Specimen Area	Specimen Volume	Volume after Cons	Height after Cons	Diameter after Cons	Volume Solid	Volume Voids	Void Ratio	Dry Unit Weight
	(g)	(%)	(g/cm^3)	(cm)	(cm)	(cm^2)	(cm^3)	(cm^3)	(cm)	(cm)	(cm^3)	(cm^3)	e_o	(g/cm^3)
	967.8	25.45	2.7	14.7	7.3	41.85	615.25	586.41	14.60	7.15	285.73	300.68	1.052	1.32
Reading	Axial Deflection	Axial Strain	Volume Change	Corrected VC	Volume Change	Corrected Area	Axial Load	Axial Load	Axial Stress	σ_1	p	q		
	(in)	(%)	(cm^3)	(cm^3)	(%)	(cm^2)		(lb)	(kPa)	(kPa)	(kPa)	(kPa)		
704	0.041	0	49.3	0	0	40.2	0.3	3	0	206.84	206.84	0		
703	0.062	0.365	49.2	-0.32	-0.05	40.3	2.5	25	24.26	231.11	218.97	12.13		
702	0.087	0.800	49.1	-0.69	-0.12	40.5	4.4	44	44.99	251.84	229.34	22.50		
708	0.111	1.218	49.6	-0.56	-0.10	40.7	12	120	127.88	334.73	270.78	63.94		
717	0.135	1.635	50.2	-0.22	-0.04	40.8	17.9	179	191.67	398.51	302.68	95.84		
724	0.16	2.070	50.7	-0.03	0.00	41.0	22	220	235.35	442.20	324.52	117.68		
731	0.185	2.505	51.2	0.16	0.03	41.2	24.9	249	265.71	472.55	339.70	132.85		
735	0.209	2.923	51.5	0.15	0.03	41.4	27	270	287.15	493.99	350.42	143.57		
738	0.234	3.357	51.7	0.06	0.01	41.6	28.6	286	302.95	509.79	358.32	151.47		
741	0.259	3.792	51.9	-0.03	0.00	41.7	29.8	298	314.32	521.17	364.00	157.16		
743	0.284	4.227	52.0	-0.19	-0.03	41.9	30.7	307	322.36	529.20	368.02	161.18		
743	0.308	4.645	52.0	-0.47	-0.08	42.2	31.6	316	330.30	537.14	371.99	165.15		
744	0.333	5.080	52.1	-0.70	-0.12	42.4	32.3	323	336.01	542.85	374.85	168.01		
745	0.357	5.497	52.2	-0.92	-0.16	42.6	33	330	341.72	548.57	377.70	170.86		
745	0.382	5.932	52.2	-1.22	-0.21	42.8	33.6	336	346.22	553.06	379.95	173.11		
745	0.407	6.367	52.2	-1.52	-0.26	43.0	34.3	343	351.68	558.52	382.68	175.84		
745	0.432	6.802	52.2	-1.82	-0.31	43.2	34.8	348	355.01	561.85	384.35	177.51		
745	0.456	7.219	52.2	-2.11	-0.36	43.4	35.3	353	358.37	565.21	386.03	179.18		
745	0.481	7.654	52.2	-2.41	-0.41	43.7	35.8	358	361.60	568.44	387.64	180.80		
744	0.506	8.089	52.1	-2.78	-0.47	43.9	36.2	362	363.72	570.57	388.70	181.86		
742	0.531	8.524	51.9	-3.22	-0.55	44.1	36.7	367	366.77	573.61	390.23	183.39		
741	0.556	8.959	51.9	-3.59	-0.61	44.4	37.1	371	368.81	575.65	391.25	184.40		
739	0.581	9.394	51.7	-4.03	-0.69	44.6	37.4	374	369.76	576.60	391.72	184.88		
737	0.606	9.829	51.6	-4.47	-0.76	44.9	37.8	378	371.68	578.52	392.68	185.84		
735	**0.631**	**10.264**	**51.5**	**-4.91**	**-0.84**	**45.1**	**38.2**	**382**	373.55	**580.39**	**393.62**	**186.78**		
733	0.656	10.699	51.3	-5.35	-0.91	45.4	38.5	385	374.40	581.25	394.05	187.20		
730	0.681	11.134	51.1	-5.86	-1.00	45.6	38.9	389	376.16	583.00	394.92	188.08		
728	0.705	11.551	51.0	-6.29	-1.07	45.9	39.1	391	376.06	582.90	394.87	188.03		
725	0.73	11.986	50.8	-6.80	-1.16	46.2	39.4	394	376.78	583.62	395.23	188.39		
722	0.755	12.421	50.5	-7.31	-1.25	46.4	39.7	397	377.47	584.31	395.58	188.74		
719	0.78	12.856	50.3	-7.82	-1.33	46.7	39.9	399	377.18	584.02	395.43	188.59		
716	0.805	13.291	50.1	-8.33	-1.42	47.0	40.2	402	377.81	584.66	395.75	188.91		
713	0.83	13.726	49.9	-8.84	-1.51	47.3	40.5	405	378.42	585.26	396.05	189.21		
710	0.854	14.143	49.7	-9.34	-1.59	47.5	40.7	407	378.15	584.99	395.92	189.07		
706	0.879	14.578	49.4	-9.92	-1.69	47.8	41	410	378.66	585.50	396.17	189.33		
703	0.905	15.030	49.2	-10.44	-1.78	48.1	41.3	413	379.10	585.94	396.39	189.55		
700	0.929	15.448	49.0	-10.94	-1.86	48.4	41.5	415	378.76	585.60	396.22	189.38		
697	0.954	15.883	48.8	-11.45	-1.95	48.7	41.8	418	379.23	586.07	396.46	189.61		
693	0.978	16.300	48.5	-12.01	-2.05	49.0	41.9	419	377.90	584.74	395.79	188.95		
689	1.004	16.752	48.2	-12.61	-2.15	49.3	42.1	421	377.29	584.13	395.49	188.64		
686	1.029	17.187	48.0	-13.12	-2.24	49.6	42.4	424	377.69	584.53	395.69	188.85		
683	1.053	17.605	47.8	-13.61	-2.32	49.9	42.6	426	377.26	584.10	395.47	188.63		
679	1.079	18.057	47.5	-14.21	-2.42	50.2	42.8	428	376.59	583.43	395.14	188.29		
675	1.103	18.475	47.3	-14.77	-2.52	50.5	43	430	376.08	582.92	394.88	188.04		
671	1.128	18.910	47.0	-15.35	-2.62	50.8	43.1	431	374.59	581.43	394.14	187.29		
668	1.153	19.345	46.8	-15.86	-2.71	51.1	43.3	433	374.00	580.84	393.84	187.00		
664	1.177	19.762	46.5	-16.43	-2.80	51.5	43.5	435	373.44	580.29	393.57	186.72		
660	1.203	20.214	46.2	-17.02	-2.90	51.8	43.7	437	372.69	579.54	393.19	186.35		
657	1.228	20.649	46.0	-17.53	-2.99	52.1	43.8	438	371.20	578.04	392.44	185.60		
653	1.253	21.084	45.7	-18.11	-3.09	52.5	43.9	439	369.66	576.50	391.67	184.83		
649	1.278	21.519	45.4	-18.69	-3.19	52.8	44.1	441	368.96	575.80	391.32	184.48		
645	1.302	21.937	45.2	-19.26	-3.28	53.1	44.1	441	366.65	573.49	390.17	183.32		
642	1.327	22.371	44.9	-19.77	-3.37	53.5	44.3	443	365.96	572.81	389.82	182.98		
638	1.352	22.806	44.7	-20.35	-3.47	53.8	44.3	443	363.56	570.41	388.63	181.78		
634	1.377	23.241	44.4	-20.93	-3.57	54.2	44.4	444	361.99	568.83	387.84	181.00		
631	1.402	23.676	44.2	-21.44	-3.66	54.5	44.5	445	360.45	567.30	387.07	180.23		
626	1.426	24.094	43.8	-22.08	-3.77	54.9	44.6	446	358.92	565.76	386.30	179.46		
623	1.451	24.529	43.6	-22.59	-3.85	55.3	44.7	447	357.37	564.21	385.53	178.68		

CD30 Test Results

Harrison County

Sample No. 2457/B5/2
Test Date : 10/13/99



CD10 Test Results

Harrison County

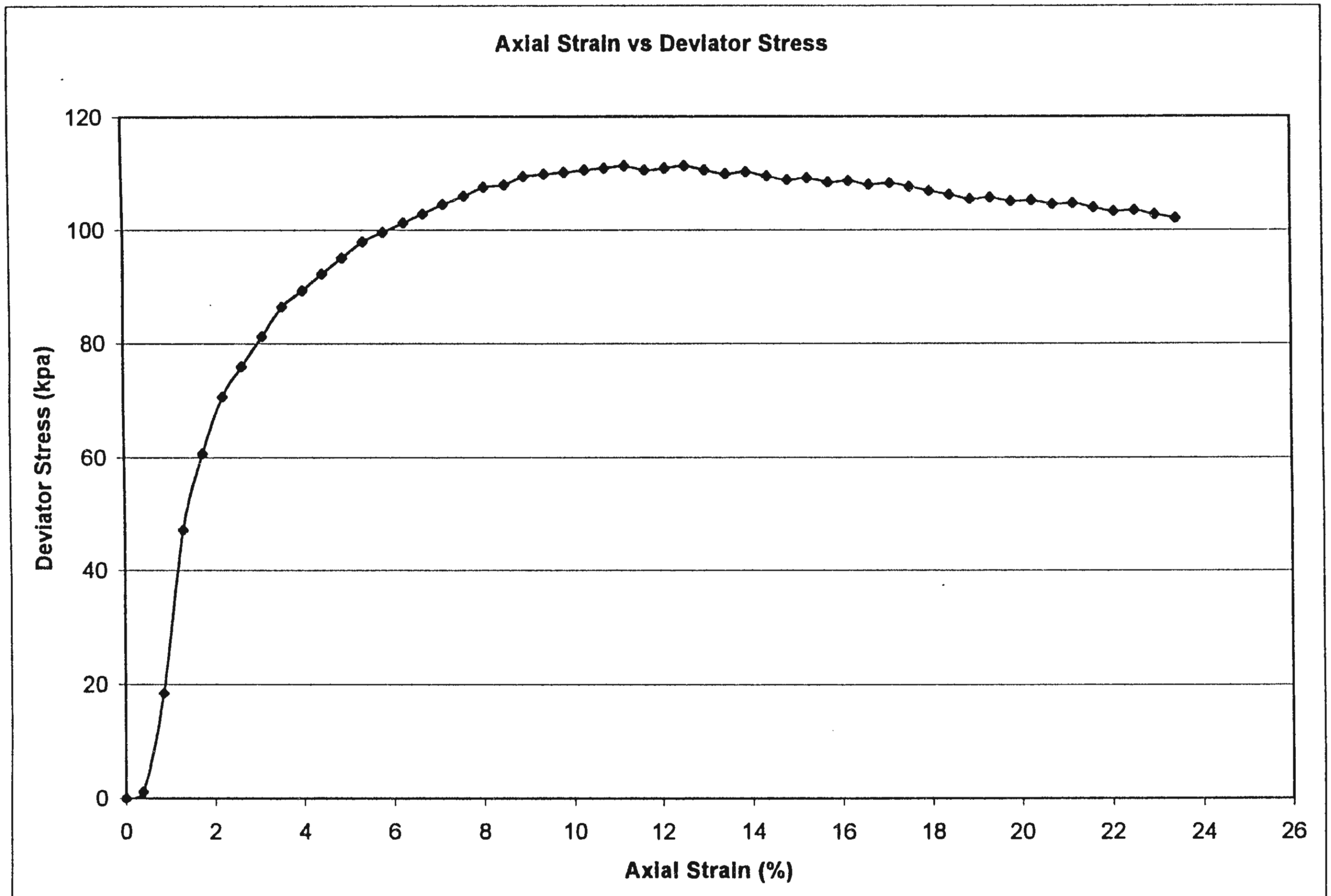
Sample No. 2457/c1/1
Test Date : 10/18/99

	Consolidated-drained test on loess													
	Test No.	3												
	Name	cd10	2457/C1/1											
	Initial	Initial	Initial	Confining	Confining	Bef. Cons	Af. Cons	Bef. Cons	Af. Cons	Void	Dry Unit	Dry Unit	Dry Unit	
	Height	Diamete	Volume	Pressure	Pressure	VC	VC	H	H	Ratio	Weight	Weight	Weight	
	141	72.1	575.68	10	68.95	32.27	75.6	0	0.056	ei	(g/cm^3)	(pcf)	(pcf)	
	(mm)	(mm)	(cm^3)	(psi)	(kPa)	(cm^3)	(cm^3)	(in)	(in)	1.205	1.22	76.40	82.62	
				Bef Cons				Aft Cons						
	Specimen	Moistur	Specific	Specimen	Specimen	Specimen	Specimen	Volume	Height	Diameter	Volume	Volume	Void	Dry Unit
	Weight	Content	Gravity	Height	Diameter	Area	Volume	after Cons	after Cons	after Cons	Solid	Voids	Ratio	Weight
	(g)	(%)	(g/cm^3)	(cm)	(cm)	(cm^2)	(cm^3)	(cm^3)	(cm)	(cm)	(cm^3)	(cm^3)	e_o	(g/cm^3)
	915.3	29.86	2.7	14.1	7.21	40.83	575.68	532.35	13.96	6.97	261.05	271.30	1.039	1.32
Reading	Axial	Axial	Volume	Corrected	Volume	Corrected	Axial	Axial	Axial	σ_1	p	q		
	Deflection	Strain	Change	VC	Change	Area	Load	Load	Stress					
	(in)	(%)	(cm^3)	(cm^3)	(%)	(cm^2)		(lb)	(kPa)	(kPa)	(kPa)	(kPa)		
1073	0.056	0	75.1	0	0	38.1	0.2	2	0	68.95	68.95	0		
1073	0.056	0	75.1	0	0	38.1	0.2	2	0	68.95	68.95	0		
1070	0.077	0.382	74.9	-0.46	-0.09	38.3	0.3	3	1.16	70.11	69.53	0.58		
1069	0.103	0.855	74.8	-0.84	-0.16	38.5	1.8	18	18.47	87.42	78.18	9.24		
1076	0.127	1.292	75.3	-0.64	-0.12	38.7	4.3	43	47.14	116.09	92.52	23.57		
1082	0.152	1.747	75.7	-0.52	-0.10	38.9	5.5	55	60.67	129.62	99.28	30.34		
1087	0.177	2.202	76.1	-0.47	-0.09	39.0	6.4	64	70.66	139.60	104.28	35.33		
1091	0.201	2.639	76.4	-0.48	-0.09	39.2	6.9	69	76.01	144.96	106.95	38.01		
1093	0.226	3.094	76.5	-0.64	-0.12	39.4	7.4	74	81.28	150.22	109.59	40.64		
1094	0.251	3.549	76.6	-0.87	-0.16	39.6	7.9	79	86.48	155.42	112.19	43.24		
1095	0.276	4.004	76.7	-1.10	-0.21	39.8	8.2	82	89.38	158.33	113.64	44.69		
1096	0.3	4.440	76.7	-1.32	-0.25	40.0	8.5	85	92.28	161.22	115.09	46.14		
1095	0.325	4.895	76.7	-1.69	-0.32	40.2	8.8	88	95.09	164.04	116.49	47.54		
1096	0.35	5.350	76.7	-1.92	-0.36	40.4	9.1	91	97.89	166.84	117.89	48.95		
1095	0.375	5.805	76.7	-2.29	-0.43	40.7	9.3	93	99.54	168.49	118.72	49.77		
1095	0.4	6.260	76.7	-2.59	-0.49	40.9	9.5	95	101.18	170.13	119.54	50.59		
1095	0.424	6.697	76.7	-2.88	-0.54	41.1	9.7	97	102.82	171.77	120.36	51.41		
1094	0.449	7.152	76.6	-3.25	-0.61	41.3	9.9	99	104.40	173.35	121.15	52.20		
1092	0.475	7.625	76.4	-3.70	-0.69	41.6	10.1	101	105.92	174.87	121.91	52.96		
1090	0.499	8.062	76.3	-4.13	-0.78	41.8	10.3	103	107.47	176.41	122.68	53.73		
1088	0.524	8.517	76.2	-4.57	-0.86	42.0	10.4	104	107.90	176.85	122.90	53.95		
1086	0.548	8.953	76.0	-4.99	-0.94	42.3	10.6	106	109.41	178.36	123.65	54.70		
1083	0.573	9.408	75.8	-5.50	-1.03	42.5	10.7	107	109.80	178.75	123.85	54.90		
1080	0.598	9.863	75.6	-6.01	-1.13	42.8	10.8	108	110.19	179.14	124.04	55.09		
1077	**0.623**	**10.318**	**75.4**	**-6.52**	**-1.23**	**43.0**	**10.9**	**109**	110.56	**179.51**	**124.23**	**55.28**		
1074	0.648	10.773	75.2	-7.03	-1.32	43.3	11	110	110.92	179.87	124.41	55.46		
1071	0.673	11.228	75.0	-7.54	-1.42	43.6	11.1	111	111.28	180.22	124.59	55.64		
1068	0.698	11.683	74.8	-8.05	-1.51	43.8	11.1	111	110.60	179.55	124.25	55.30		
1065	0.723	12.138	74.6	-8.56	-1.61	44.1	11.2	112	110.94	179.88	124.42	55.47		
1062	0.747	12.575	74.3	-9.06	-1.70	44.4	11.3	113	111.28	180.23	124.59	55.64		
1058	0.772	13.030	74.1	-9.64	-1.81	44.6	11.3	113	110.59	179.53	124.24	55.29		
1055	0.797	13.485	73.9	-10.15	-1.91	44.9	11.3	113	109.91	178.85	123.90	54.95		
1051	0.822	13.939	73.6	-10.73	-2.02	45.2	11.4	114	110.19	179.14	124.04	55.10		
1048	0.847	14.394	73.4	-11.24	-2.11	45.5	11.4	114	109.51	178.46	123.70	54.75		
1045	0.872	14.849	73.2	-11.75	-2.21	45.8	11.4	114	108.83	177.77	123.36	54.41		
1041	0.896	15.286	72.9	-12.32	-2.31	46.1	11.5	115	109.12	178.07	123.51	54.56		
1038	0.921	15.741	72.7	-12.83	-2.41	46.4	11.5	115	108.43	177.38	123.16	54.22		
1035	0.946	16.196	72.5	-13.34	-2.51	46.7	11.6	116	108.70	177.65	123.30	54.35		
1032	0.971	16.651	72.2	-13.85	-2.60	46.9	11.6	116	108.01	176.96	122.95	54.00		
1028	0.997	17.124	72.0	-14.44	-2.71	47.3	11.7	117	108.22	177.17	123.06	54.11		
1025	1.021	17.561	71.8	-14.94	-2.81	47.6	11.7	117	107.55	176.50	122.72	53.78		
1021	1.045	17.998	71.5	-15.51	-2.91	47.9	11.7	117	106.87	175.82	122.38	53.44		
1018	1.07	18.453	71.3	-16.02	-3.01	48.2	11.7	117	106.18	175.13	122.04	53.09		
1014	1.095	18.907	71.0	-16.60	-3.12	48.5	11.7	117	105.48	174.42	121.69	52.74		
1011	1.12	19.362	70.8	-17.11	-3.21	48.8	11.8	118	105.70	174.65	121.80	52.85		
1008	1.145	19.817	70.6	-17.62	-3.31	49.1	11.8	118	105.00	173.95	121.45	52.50		
1004	1.17	20.272	70.3	-18.20	-3.42	49.5	11.9	119	105.20	174.14	121.55	52.60		
1000	1.195	20.727	70.0	-18.78	-3.53	49.8	11.9	119	104.49	173.43	121.19	52.24		
997	1.22	21.182	69.8	-19.29	-3.62	50.1	12	120	104.68	173.63	121.29	52.34		
994	1.245	21.637	69.6	-19.80	-3.72	50.5	12	120	103.98	172.93	120.94	51.99		
990	1.27	22.092	69.3	-20.38	-3.83	50.8	12	120	103.27	172.21	120.58	51.63		
987	1.295	22.547	69.1	-20.89	-3.92	51.2	12.1	121	103.44	172.38	120.67	51.72		
983	1.32	23.002	68.8	-21.47	-4.03	51.5	12.1	121	102.72	171.67	120.31	51.36		
979	1.345	23.457	68.5	-22.05	-4.14	51.9	12.1	121	102.01	170.96	119.95	51.00		

CD10 Test Results

Harrison County

Sample No. 2457/C1/1
Test Date : 10/18/99



Consolidated-drained test on loess

Test No.	9	
Name	cd30	2457/C1/2

Initial Height	Initial Diamete	Initial Volume	Confining Pressure	Confining Pressure	Bef. Cons VC	Af. Cons VC	Bef. Cons H	Af. Cons H	Void Ratio	Dry Unit Weight	Dry Unit Weight	Dry Unit Weight (pcf)
152	70.1	586.64	30	206.84	45.64	94.5	0.01	0.069	ei	(g/cm^3)	(pcf)	
(mm)	(mm)	(cm^3)	(psi)	(kPa)	(cm^3)	(cm^3)	(in)	(in)	1.049	1.32	82.24	89.71

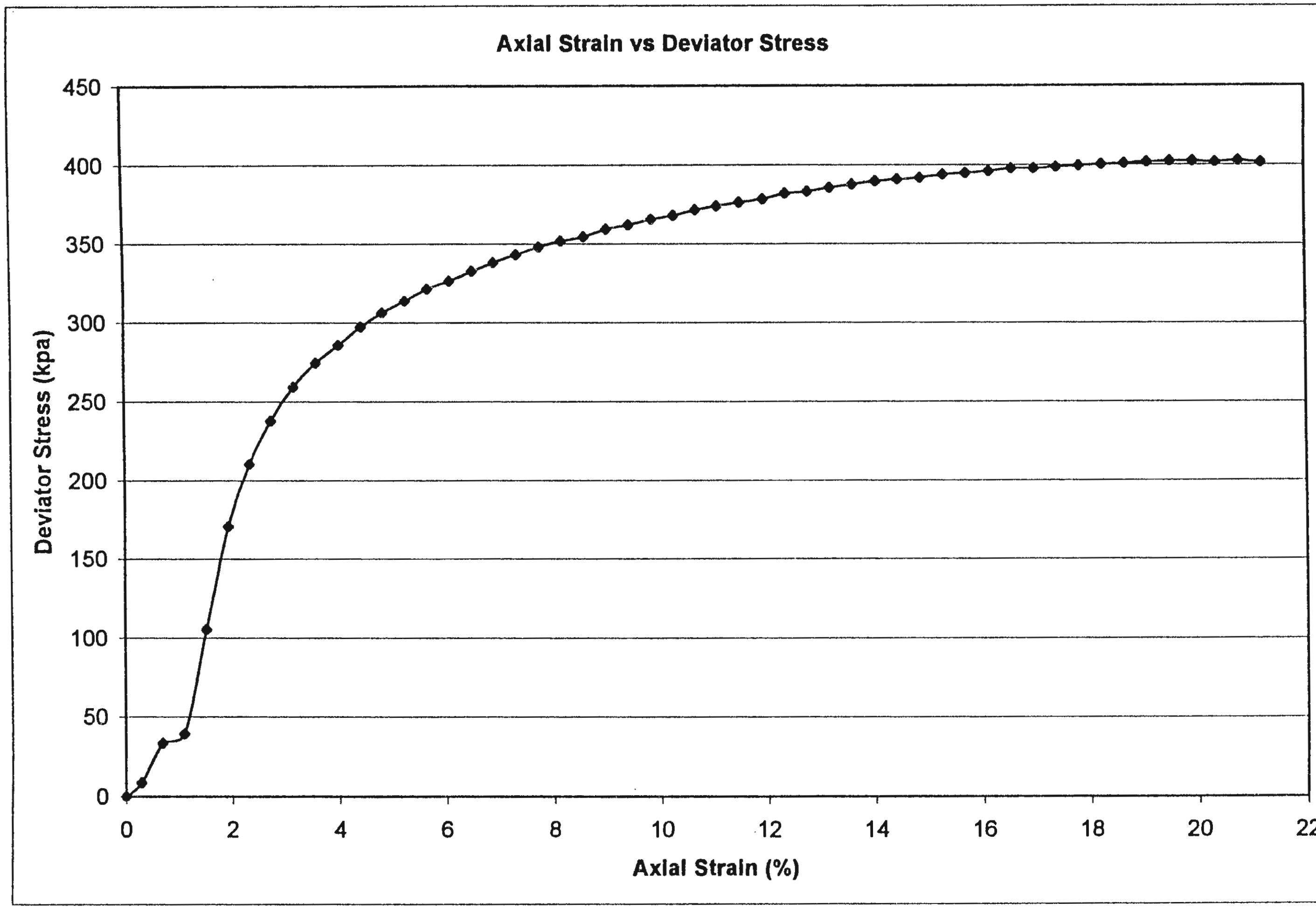
			Bef Cons				Aft Cons						
Specimen Weight (g)	Moistur Content (%)	Specific Gravity (g/cm^3)	Specimen Height (cm)	Specimen Diameter (cm)	Specimen Area (cm^2)	Specimen Volume (cm^3)	Volume after Cons (cm^3)	Height after Cons (cm)	Diameter after Cons (cm)	Volume Solid (cm^3)	Volume Voids (cm^3)	Void Ratio e_o	Dry Unit Weight (g/cm^3)
990	28.05	2.7	15.2	7.01	38.59	586.64	537.78	15.05	6.75	286.35	251.43	0.878	1 44

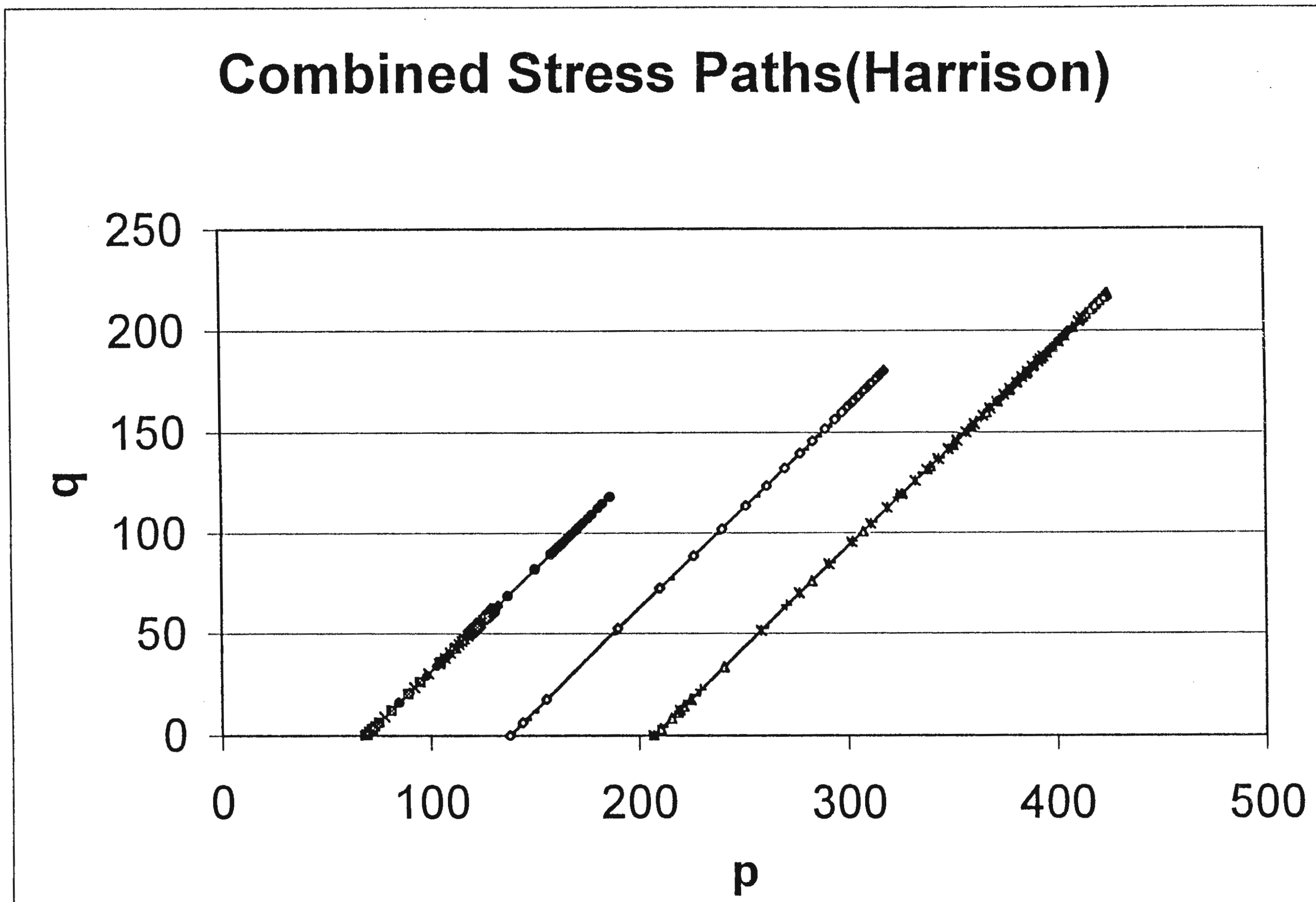
Reading	Axial Deflection (in)	Axial Strain (%)	Volume Change (cm^3)	Corrected VC (cm^3)	Volume Change (%)	Corrected Area (cm^2)	Axial Load	Axial Load (lb)	Axial Stress (kPa)	σ_1 (kPa)	p (kPa)	q (kPa)
1350	0.069	0	94.5	0	0	35.7	0.2	2	0	206.84	206.84	0
1350	0.069	0.000	94.5	0.00	0.00	35.7	0.2	2	0	206.84	206.84	0.00
1349	0.069	0.000	94.4	-0.07	-0.01	35.7	0.2	2	0	206.84	206.84	0.00
1352	0.086	0.287	94.6	-0.06	-0.01	35.8	0.9	9	8.69	215.53	211.19	4.34
1353	0.11	0.692	94.7	-0.28	-0.05	36.0	2.9	29	33.36	240.20	223.52	16.68
1354	0.134	1.097	94.8	-0.50	-0.09	36.2	3.4	34	39.36	246.21	226.52	19.68
1352	0.159	1.519	94.6	-0.94	-0.17	36.3	8.8	88	105.25	312.09	259.47	52.62
1341	0.183	1.924	93.9	-2.00	-0.37	36.6	14.2	142	170.30	377.14	291.99	85.15
1330	0.207	2.329	93.1	-3.06	-0.57	36.8	17.6	176	210.37	417.21	312.03	105.18
1322	0.231	2.734	92.5	-3.90	-0.73	37.0	20	200	238.02	444.86	325.85	119.01
1314	0.256	3.156	92.0	-4.76	-0.89	37.2	21.9	219	259.31	466.16	336.50	129.66
1308	0.281	3.578	91.6	-5.48	-1.02	37.4	23.3	233	274.48	481.32	344.08	137.24
1303	0.306	4.000	91.2	-6.13	-1.14	37.6	24.4	244	285.95	492.79	349.82	142.97
1298	0.331	4.422	90.9	-6.78	-1.26	37.9	25.5	255	297.28	504.12	355.48	148.64
1295	0.355	4.827	90.7	-7.28	-1.35	38.1	26.4	264	306.27	513.11	359.98	153.13
1292	0.38	5.249	90.4	-7.79	-1.45	38.3	27.2	272	313.92	520.77	363.81	156.96
1289	0.405	5.671	90.2	-8.30	-1.54	38.5	28	280	321.49	528.33	367.59	160.74
1286	0.43	6.093	90.0	-8.81	-1.64	38.7	28.6	286	326.65	533.49	370.17	163.33
1284	0.455	6.514	89.9	-9.25	-1.72	38.9	29.3	293	332.93	539.77	373.31	166.47
1282	0.479	6.920	89.7	-9.68	-1.80	39.1	29.9	299	338.06	544.90	375.87	169.03
1281	0.504	7.341	89.7	-10.05	-1.87	39.3	30.5	305	343.09	549.94	378.39	171.55
1280	0.529	7.763	89.6	-10.42	-1.94	39.5	31.1	311	348.06	554.90	380.87	174.03
1279	0.554	8.185	89.5	-10.79	-2.01	39.7	31.6	316	351.83	558.68	382.76	175.92
1279	0.579	8.607	89.5	-11.09	-2.06	39.9	32	320	354.49	561.33	384.09	177.24
1279	0.604	9.029	89.5	-11.39	-2.12	40.1	32.6	326	359.31	566.15	386.50	179.66
1279	0.629	9.451	89.5	-11.69	-2.17	40.3	33	330	361.86	568.70	387.77	180.93
1278	0.654	9.873	89.5	-12.06	-2.24	40.5	33.5	335	365.42	572.26	389.55	182.71
1278	**0.679**	**10.295**	**89.5**	**-12.36**	**-2.30**	**40.7**	**33.9**	**339**	367.88	**574.72**	**390.78**	**183.94**
1279	0.703	10.700	89.5	-12.58	-2.34	40.9	34.4	344	371.50	578.35	392.59	185.75
1279	0.727	11.105	89.5	-12.87	-2.39	41.2	34.8	348	373.95	580.79	393.82	186.97
1279	0.752	11.527	89.5	-13.17	-2.45	41.4	35.2	352	376.27	583.11	394.98	188.13
1279	0.778	11.966	89.5	-13.48	-2.51	41.6	35.6	356	378.47	585.31	396.08	189.23
1280	0.803	12.388	89.6	-13.71	-2.55	41.8	36.1	361	381.81	588.66	397.75	190.91
1281	0.827	12.793	89.7	-13.93	-2.59	42.0	36.4	364	383.07	589.92	398.38	191.54
1283	0.852	13.215	89.8	-14.09	-2.62	42.3	36.8	368	385.32	592.16	399.50	192.66
1284	0.877	13.637	89.9	-14.32	-2.66	42.5	37.2	372	387.48	594.32	400.58	193.74
1286	0.902	14.058	90.0	-14.48	-2.69	42.7	37.6	376	389.64	596.48	401.66	194.82
1287	0.926	14.464	90.1	-14.69	-2.73	42.9	37.9	379	390.76	597.60	402.22	195.38
1289	0.951	14.885	90.2	-14.85	-2.76	43.1	38.2	382	391.81	598.66	402.75	195.91
1291	0.976	15.307	90.4	-15.01	-2.79	43.4	38.6	386	393.86	600.70	403.77	196.93
1292	1.001	15.729	90.4	-15.24	-2.83	43.6	38.9	389	394.80	601.64	404.24	197.40
1294	1.026	16.151	90.6	-15.40	-2.86	43.8	39.2	392	395.75	602.59	404.72	197.87
1296	1.051	16.573	90.7	-15.56	-2.89	44.1	39.6	396	397.68	604.52	405.68	198.84
1298	1.076	16.995	90.9	-15.72	-2.92	44.3	39.8	398	397.56	604.41	405.62	198.78
1300	1.1	17.400	91.0	-15.87	-2.95	44.5	40.1	401	398.51	605.36	406.10	199.26
1302	1.125	17.822	91.1	-16.03	-2.98	44.8	40.4	404	399.34	606.19	406.52	199.67
1305	1.15	18.244	91.4	-16.12	-3.00	45.0	40.7	407	400.19	607.04	406.94	200.10
1307	1.175	18.666	91.5	-16.28	-3.03	45.3	41	410	400.96	607.81	407.32	200.48
1310	1.2	19.088	91.7	-16.37	-3.04	45.5	41.3	413	401.75	608.59	407.72	200.88
1313	1.225	19.510	91.9	-16.46	-3.06	45.8	41.6	416	402.51	609.35	408.10	201.25
1316	1.25	19.932	92.1	-16.55	-3.08	46.0	41.8	418	402.27	609.11	407.98	201.13
1318	1.275	20.354	92.3	-16.71	-3.11	46.3	42	420	401.95	608.80	407.82	200.98
1322	1.3	20.775	92.5	-16.73	-3.11	46.5	42.3	423	402.68	609.52	408.18	201.34
1325	1.325	21.197	92.8	-16.82	-3.13	46.8	42.4	424	401.42	608.26	407.55	200.71

CD10 Test Results

Harrison County

Sample No. 2457/C1 /2
Test Date : 10/13/99




Combined Stress Paths(Harrison)
q
p
250
200
150
100
50
0
0
100
200
300
400
500

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